602842

59p
k - 3.00
mf - 0.75

HIGH-TEMPERATURE ANTENNA INVESTIGATION AND DEVELOPMENT

The applied research reported in this document has been made possible through support and sponsorship extended by the Air Force Avionics Laboratory of the AFSC Research and Technology Division under Contract No. AF 33(657)-11100. It is published for technical information only and does not necessarily represent recommendations or conclusions of the sponsoring agency.

INTERIM ENGINEERING REPORT NO. 5

By: Godfrey F. Buranich

Contract No. AF 33(657)-11100
CAL Report No. UB-1807-E-5
Period Ending 30 June 1964

Program Element No. 62405484
760-D Project 6278 Task 627802
RTD-Air Force Avionics Laboratory
Project Engineer: J.F. Ripple, Jr., AVWE

CORNELL AERONAUTICAL LABORATORY, INC.
OF CORNELL UNIVERSITY, BUFFALO 21, N. Y.

CORNELL AERONAUTICAL LABORATORY, INC.
BUFFALO, NEW YORK 14221

HIGH-TEMPERATURE ANTENNA INVESTIGATION

INTERIM ENGINEERING REPORT NO. 5
FOR QUARTER ENDING 30 JUNE 1964

PREPARED FOR
AFSC RESEARCH AND TECHNOLOGY DIVISION
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

CONTRACT NO. AF 33(657)-11100
HITCH ELEMENT NR. 62405484
760-D PROJECT NO. 6278 TASK 627802

RTD - AIR FORCE AVIONICS LABORATORY
PROJECT ENGINEER - J.F. RIPPIN, JR., AVWE

PREPARED BY: G.F. Buranich

G.F. Buranich
Project Engineer

APPROVED BY: C.W. Miller for

E.L. Price, Head
Wave Electronics Section

C.W. Miller

C.W. Miller, Head
Electronics Research Department

ABSTRACT

This quarterly report summarizes investigations which were made for developing antennas suitable for prolonged operation at a temperature of 2000°F.

The efficiencies of S-band helical antennas made of various metals were compared and no significant reduction in efficiency occurred with metals having resistivities as high as 120 microhm - cm. Tests made on nichrome and coated tantalum helical antennas at 2000°F showed no degradation with temperature.

Experimental tests for determining the relative power handling capabilities of copper, TD nickel, coated tantalum and Boride Z metals at 2000°F are being made.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS - contd.

INTRODUCTION

Manned re-entry vehicles represent the primary application for high temperature antennas. Such vehicles may attain a stagnation temperature over 3000°F but most areas of the surface do not exceed a temperature of 1500°F. These thermal environments generally require the use of nickel alloys at the lower temperatures and coated refractory metals at temperatures above 2000°F. Ceramics must be employed as insulators except that glass is usable at a temperature of 1000°F.

Information is being compiled on the properties of the materials which are suitable for antenna fabrication. Model antennas using ceramic-to-metal seals, coated refractory metals, and metallized ceramic printed spiral elements are being designed and tested at high temperature to establish design techniques and to document the high temperature performance of the completed assemblies.

The techniques of generating and maintaining a suitable thermal environment for evaluation of antenna assemblies are being developed in this program.

APPLICATIONS OF HOT ANTENNAS

Manned re-entry vehicles represent one application for antennas which must perform in a sustained thermal environment of 2000°F. A manned vehicle must re-enter the atmosphere very gradually in order not to exceed the deceleration limits which can be endured by its human occupant. As a result of this limitation, a winged vehicle re-entry time of one hour is required and although the peak temperature experienced by ballistic missiles is avoided, the prolonged heating rate produces a sustained vehicle surface temperature of 1000°F to 3000°F. The highest temperatures in re-entry are produced at the leading edges of the vehicle and appreciably lower temperatures are produced elsewhere on the body, especially along the upper surface of the vehicle. Figure 1 shows the expected equilibrium temperatures on a typical winged re-entry vehicle.

The structural temperature can be maintained at less than the surface temperature of the vehicle through the use of ablative material. However, a rather drastic reduction of vehicle weight can be realized if the structural members are made of material having suitable strength at high temperature. Figure 2 illustrates this possible reduction in weight and suggests that an appreciable advantage exists in using materials having an allowable temperature of at least 3000°F while retaining high strength.

Lifting re-entry vehicles are expected to generally attain temperatures of 1500 - 2000°F with leading edges approaching 3600°F. Current high-speed vehicles whose thermal environment received considerable attention are described in the following paragraphs together with an outline of the materials found suitable for such applications.

The ASSET vehicle is designed to evaluate materials by actual re-entry flights During re-entry it is expected to attain a nose temperature of 3700°F. A graphite-zirconium nose cap is used while panels of coated molybdenum and columbium are installed on various less intensely heated areas. A new higher-speed ASSET vehicle is under consideration.

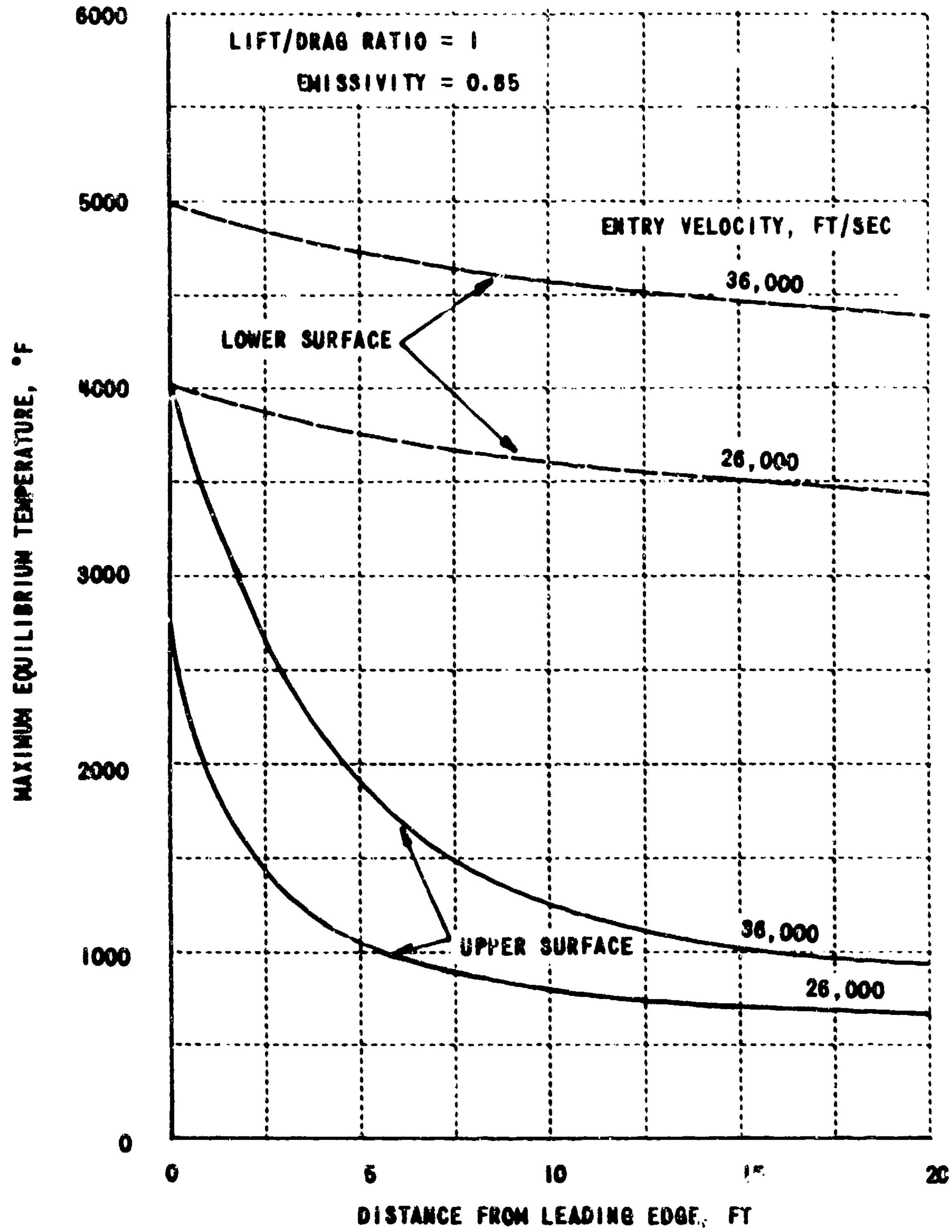


Figure 1 MAXIMUM SURFACE TEMPERATURES FOR LIFTING REENTRY VEHICLE

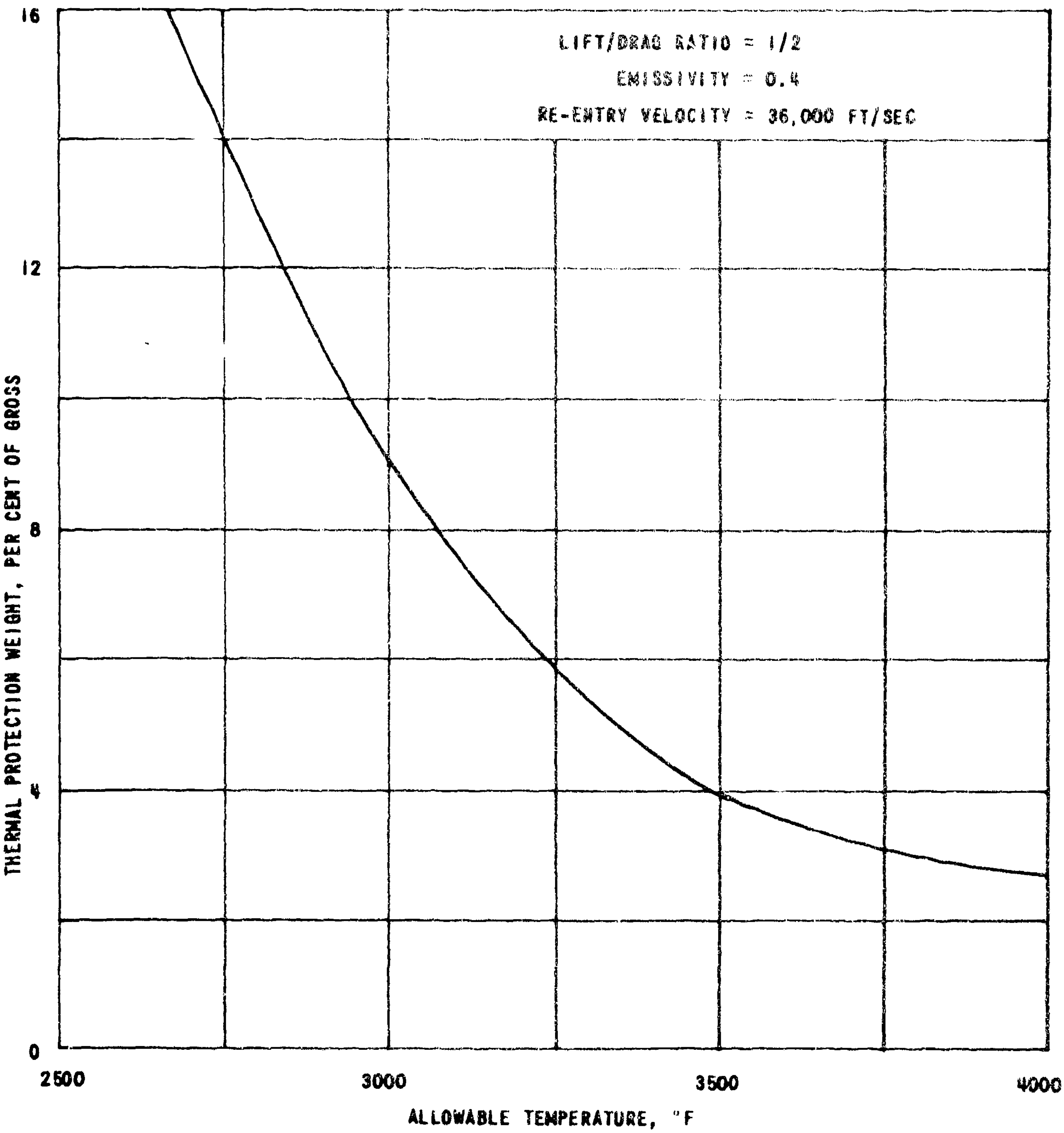


Figure 2 REDUCTION IN WEIGHT OF AN APOLLO-LIKE VEHICLE BY INCREASE IN ALLOWABLE SURFACE TEMPERATURE

The X-20 vehicle was designed to use columbium alloy at temperatures of 1900 - 2700°F and molybdenum alloy between 2700° and 3000°F.

Parawing gliders are being considered for returning spacecraft boosters to earth. These flexible or inflatable vehicles may reach peak temperatures of 3500°F for one minute, and will experience temperatures of 1000°F for extended periods of time. Woven fabrics of super alloy wire are suitable for this use.

The X-15 research aircraft employs titanium substructure and Inconel skins to withstand aerodynamic heating at speeds up to Mach 8. The modified X-15A-2 version will achieve higher speeds and will use an ablative material on the leading edges. In early tests the X-15 attained maximum temperatures of 1500°F with appreciable fuselage areas heated to 1000°F. Future flights may produce maximum temperatures of 2500°F.

The XB-70 uses titanium alloy as skin material and stainless steel honeycomb in much of the fuselage and wing sections where temperatures of 500°F or more are expected. The stabilizers have steel skins and titanium substructure . The temperature of the substructure in this area exceeds 600°F.

The Mach 3 supersonic transport will generally reach a skin temperature of only 500 - 600°F.

HIGH TEMPERATURE METALS

Metals for use at high temperatures can be categorized into four general groups. These are steels, titanium alloys, super alloys, and refractory metal alloys. Steels and titanium alloys lose much of their strength at temperatures less than 1000°F, while super alloys may be considered for applications requiring strength at 2000°F. Refractory metals can be used in thermal environments to about 4500°F. The upper limit of each of these materials is dictated to some extent by the specific proposed application and includes a consideration of fabricability, oxidation resistance, cost, weight, as well as by the peak value and duration of the high temperature environment. It is to be noted too that new alloys are being continuously developed to extend the upper temperature limit of a metal. Such extensions however usually are made at the expense of the ease of fabricability and ductility of the metal. Figure 3 shows curves of the strength/temperature relationships of the above groups of metals. The superiority of the super alloys at temperatures above 1000°F is clearly evident, as is the superiority of the refractory metals above 2500°F. The choice of materials for use at about 2000°F requires a study of specific proposed applications in order to make a suitable choice of materials. Properties of importance in specific applications are described under appropriate heading in the succeeding pages. Figures 4 and 5 show in greater detail the strength of various metals at a temperature of 1500 - 2500°F.

Composite Materials

Composite materials are mixtures of high strength materials (usually oxides or refractory metals) and metals with low melting points. The composite material retains strength to a temperature which approaches the melting point of the metal matrix. Oxidation resistance is improved at elevated temperatures. Typical of composite material is TD nickel which consists of sub-micron sized particles of thoria in a nickel matrix and a silver composite which uses whiskers of alumina in a silver matrix. The strength attained by these composites is shown in Figure 6 and 7.

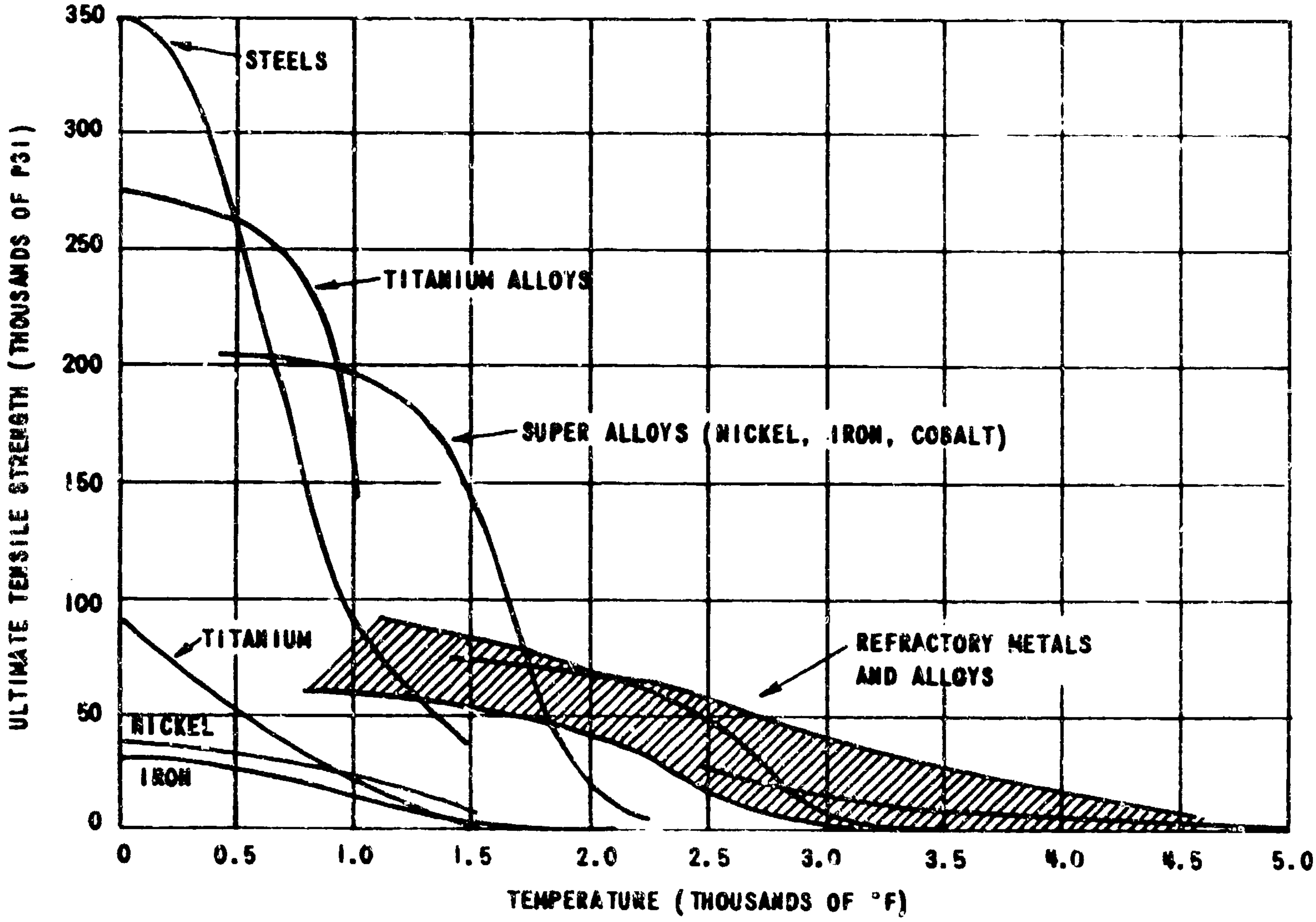


Figure 3 TENSILE STRENGTHS OF METALS AND METAL ALLOYS *Courtesy John Hopkins University*

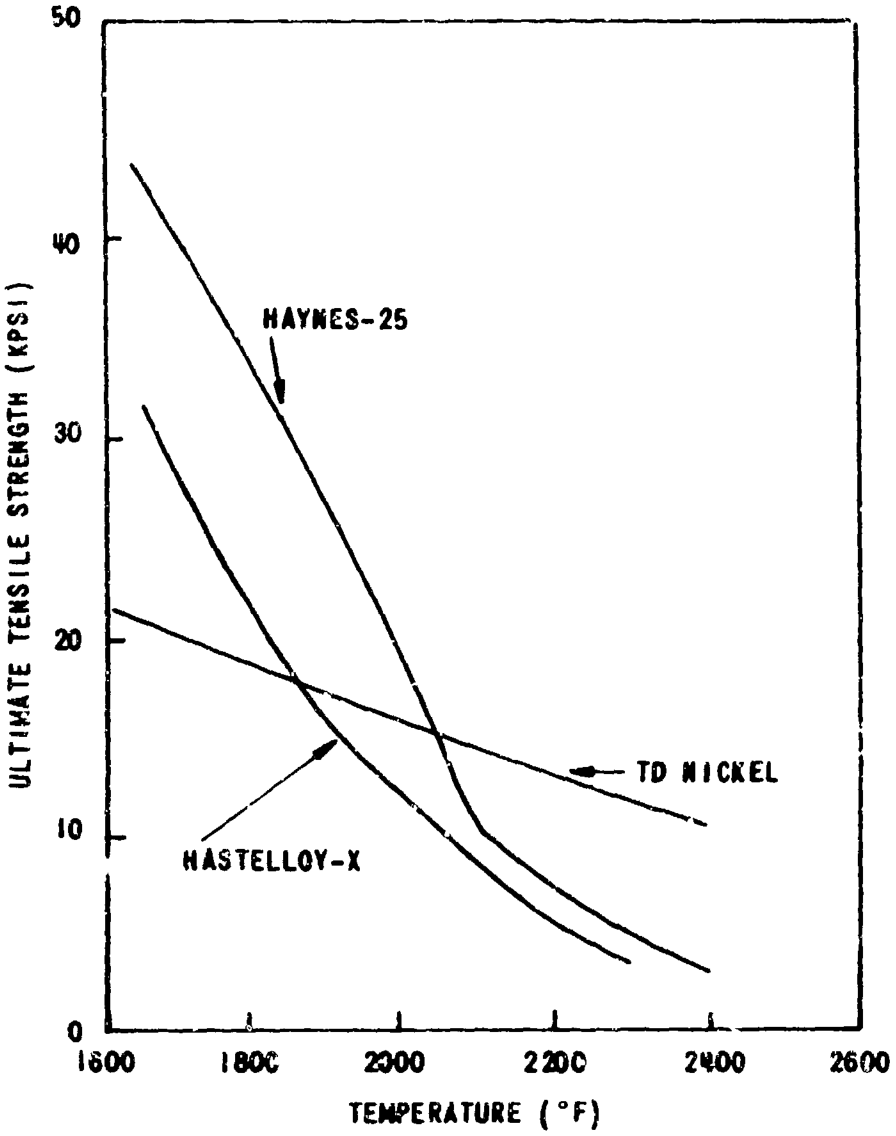


Figure 4 STRENGTH vs TEMPERATURE, SUPER ALLOYS

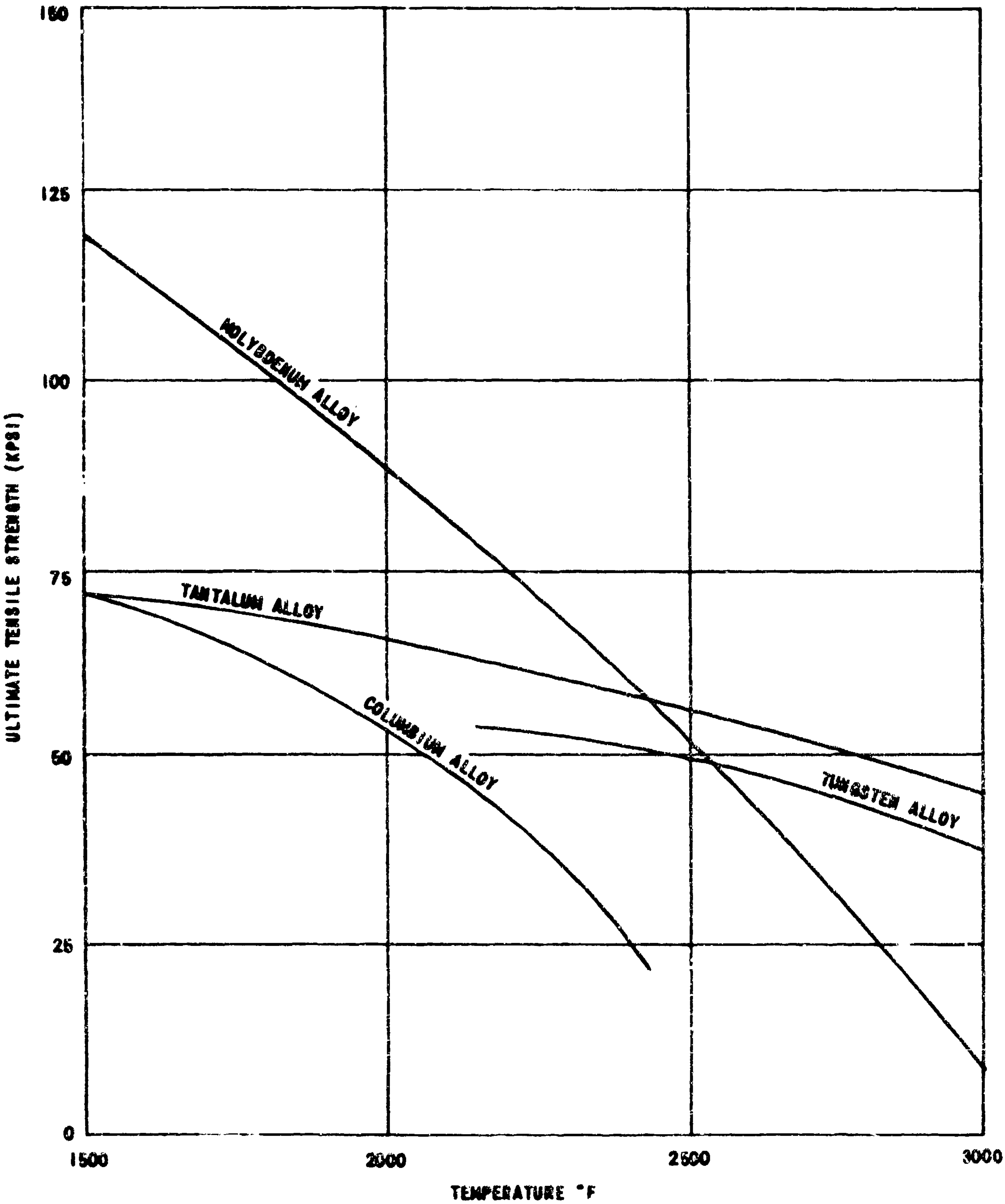


Figure 5 STRENGTH vs TEMPERATURE, REFRACTORY METALS

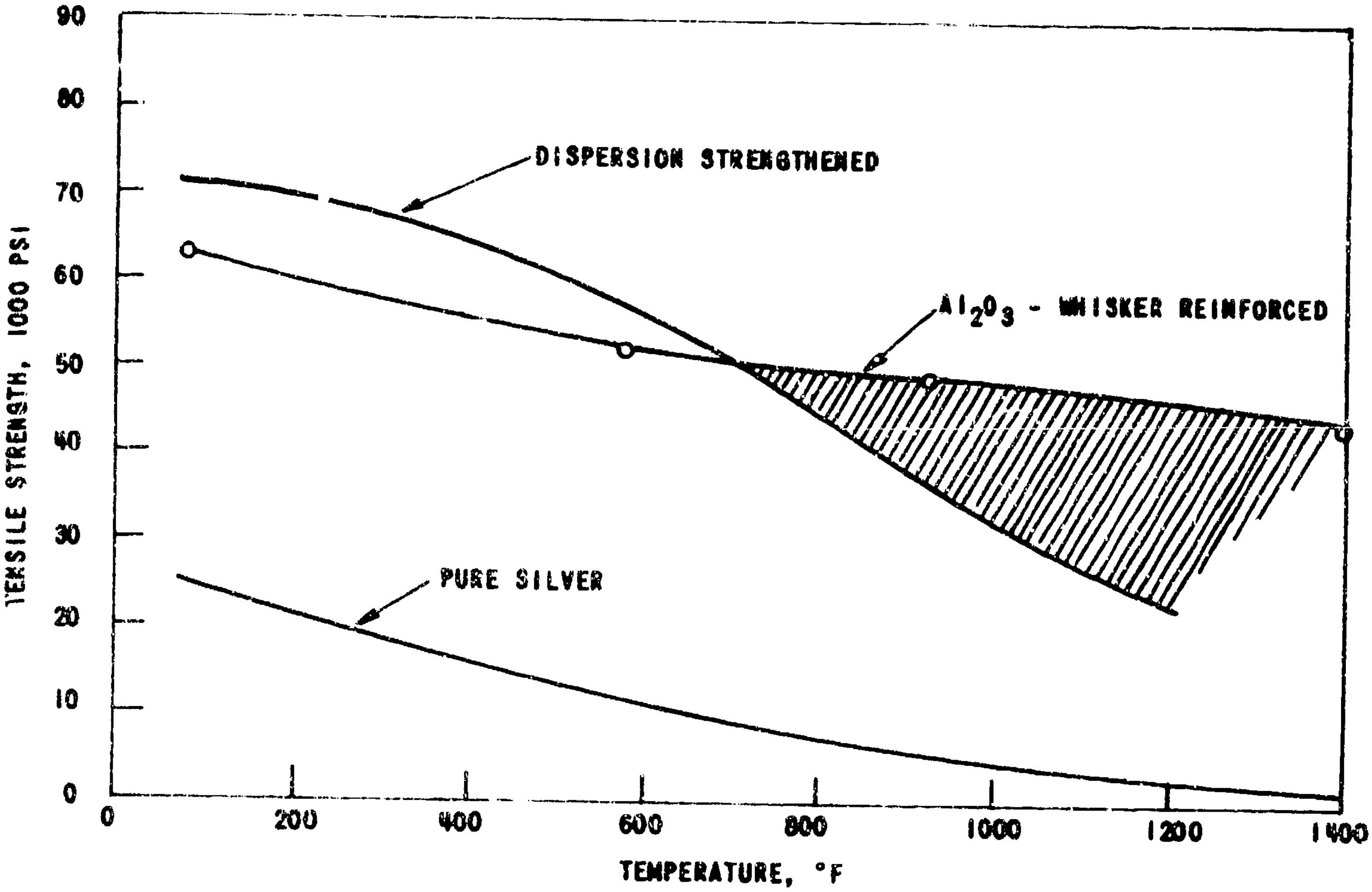


Figure 6 TENSILE STRENGTH OF SILVER AND SILVER COMPOSITES

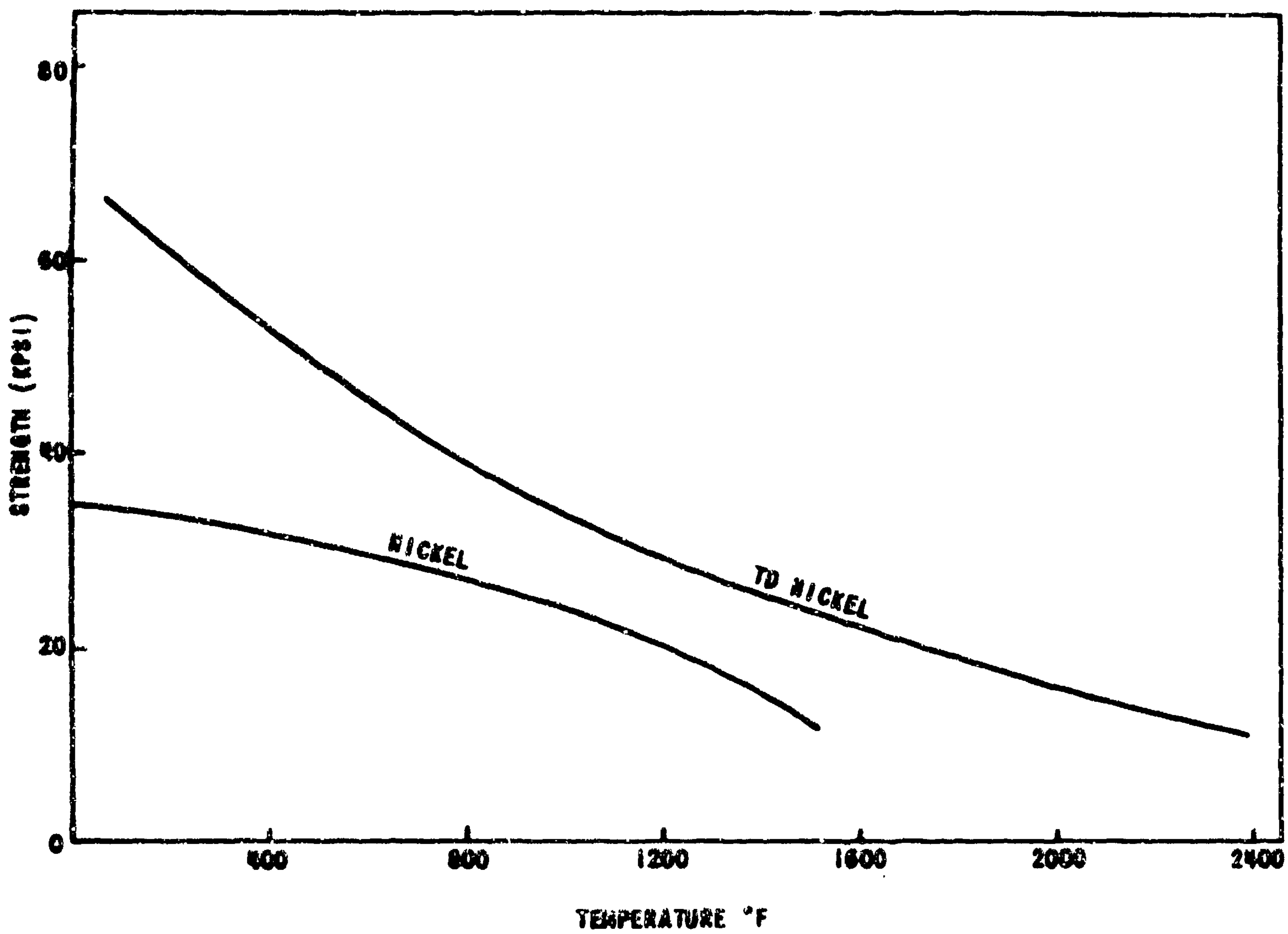


Figure 7 TENSILE STRENGTH TD NICKEL

Oxidation Resistance

Oxidation resistance is that characteristic of a material which enables it to retain a uniform (or slowly varying) weight while exposed to oxygen at high temperature. Oxidation is a process which causes a material to transform into an oxide powder or film on its surface. As a result there occurs a thinning of the base material and an obvious reduction of strength. In an extreme case this process of oxidation is similar to combustion. Such catastrophic failure of a structural member of a vehicle can occur after damage to an oxidation resistant protective coating. For this reason materials having at least limited oxidation resistance are strongly preferred for use at high temperatures in place of those which depend wholly on a protective coat.

Initial oxidation of a clean material is relatively rapid until an oxide film is formed. This film then forms a partially protective coating and subsequent oxidation proceeds much more slowly and may eventually become nil. At higher temperatures which are beyond the oxidation resistance capability of a material, this reduced oxidation rate and the attainment of a constant weight is not reached. The material in such an environment continues to oxidize (rapidly) until it is entirely consumed.

Figure 8 shows the relative oxidation resistance of representative super alloys at 2000°F. Figure 9 shows the variation of oxidation with time of TD nickel for various temperatures. At a temperature of 2400°F the oxidation remains at about a constant rate. Below this temperature the oxidation rate diminishes with time. At reduced pressures (typical of re-entry), the oxygen available in the ambient environment is low; thus, as shown, oxidation of metals is less severe than at a pressure of one atmosphere. Figure 10 shows the severe oxidation of some refractory metals as a function of temperature. The depth of oxide penetration into the metal is sometimes used as a measure of oxidation. Oxidation resistance of representative Inconel metals is shown in Figure 11.

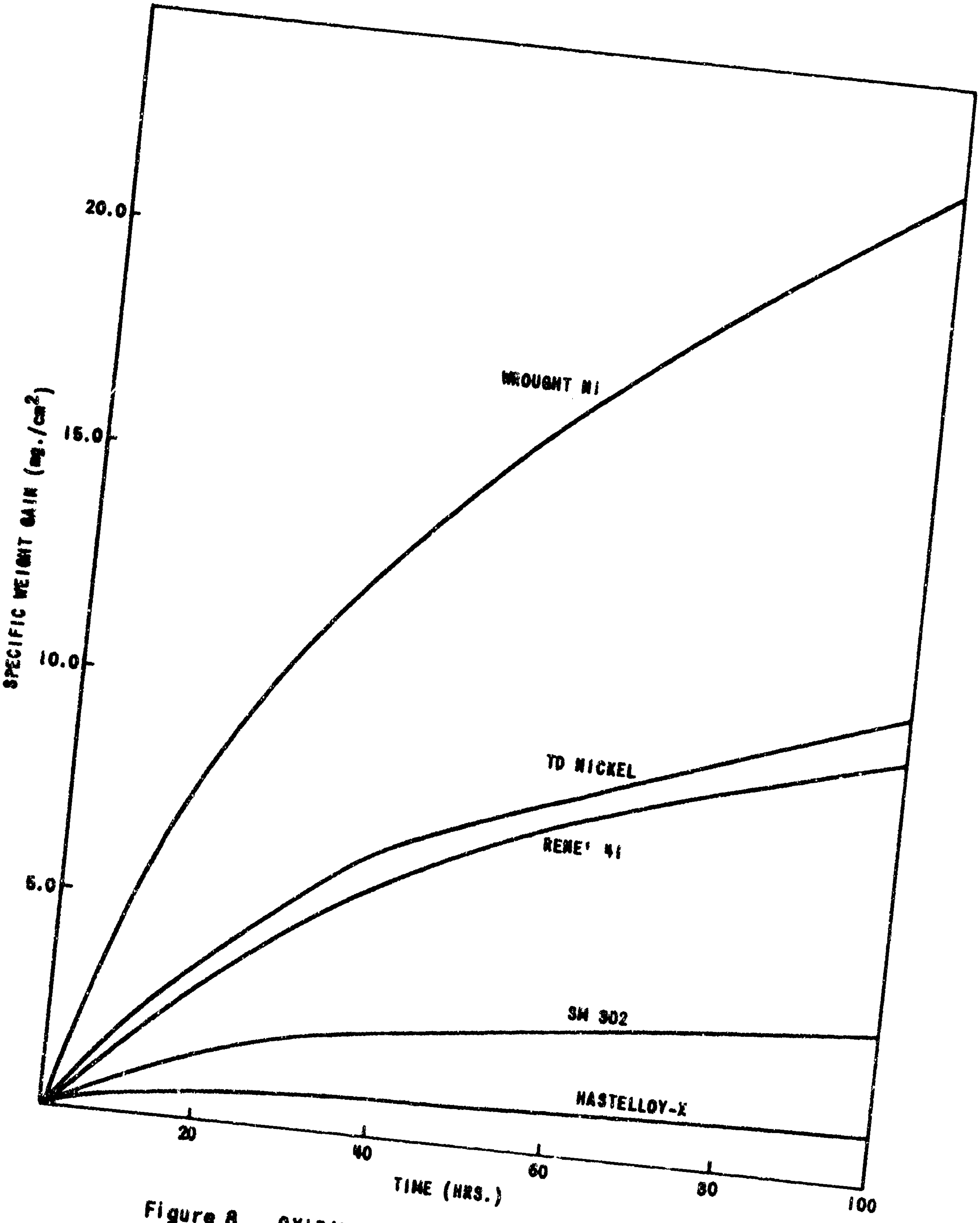


Figure 8 OXIDATION RESISTANCE - 2000° F

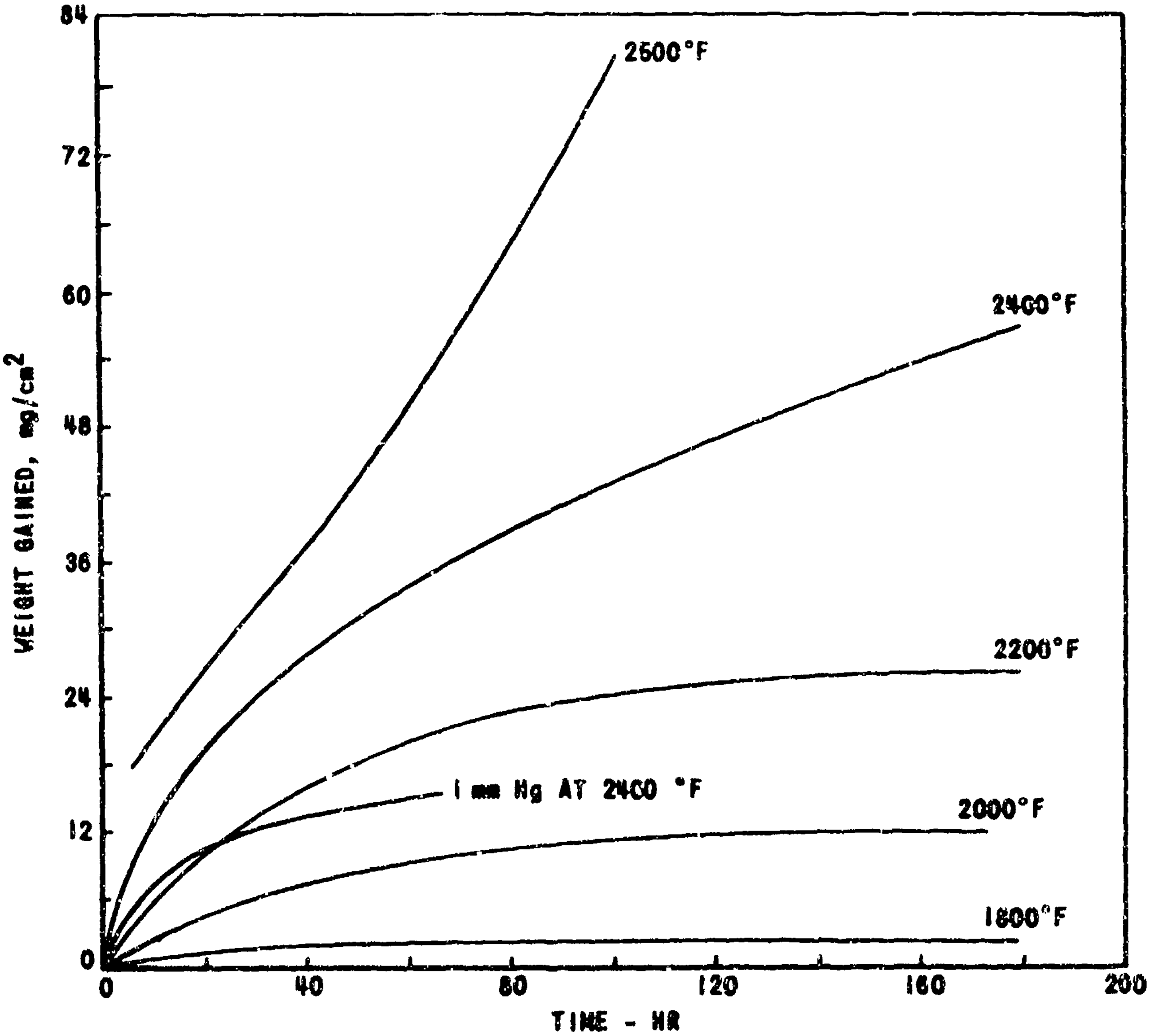


Figure 9 OXIDATION VS TIME, TD NICKEL

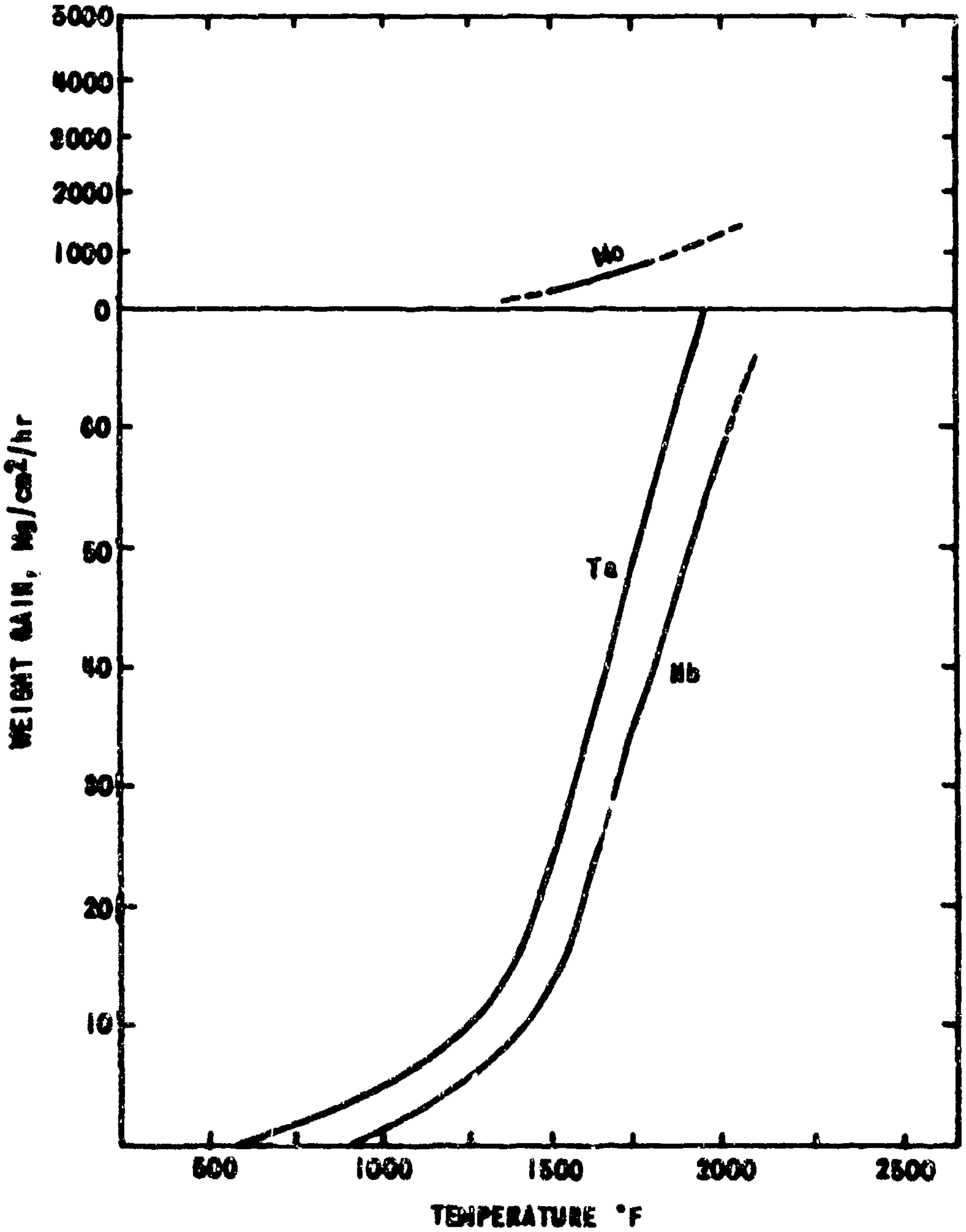


Figure 10 OXIDATION OF REFRACTORY METALS

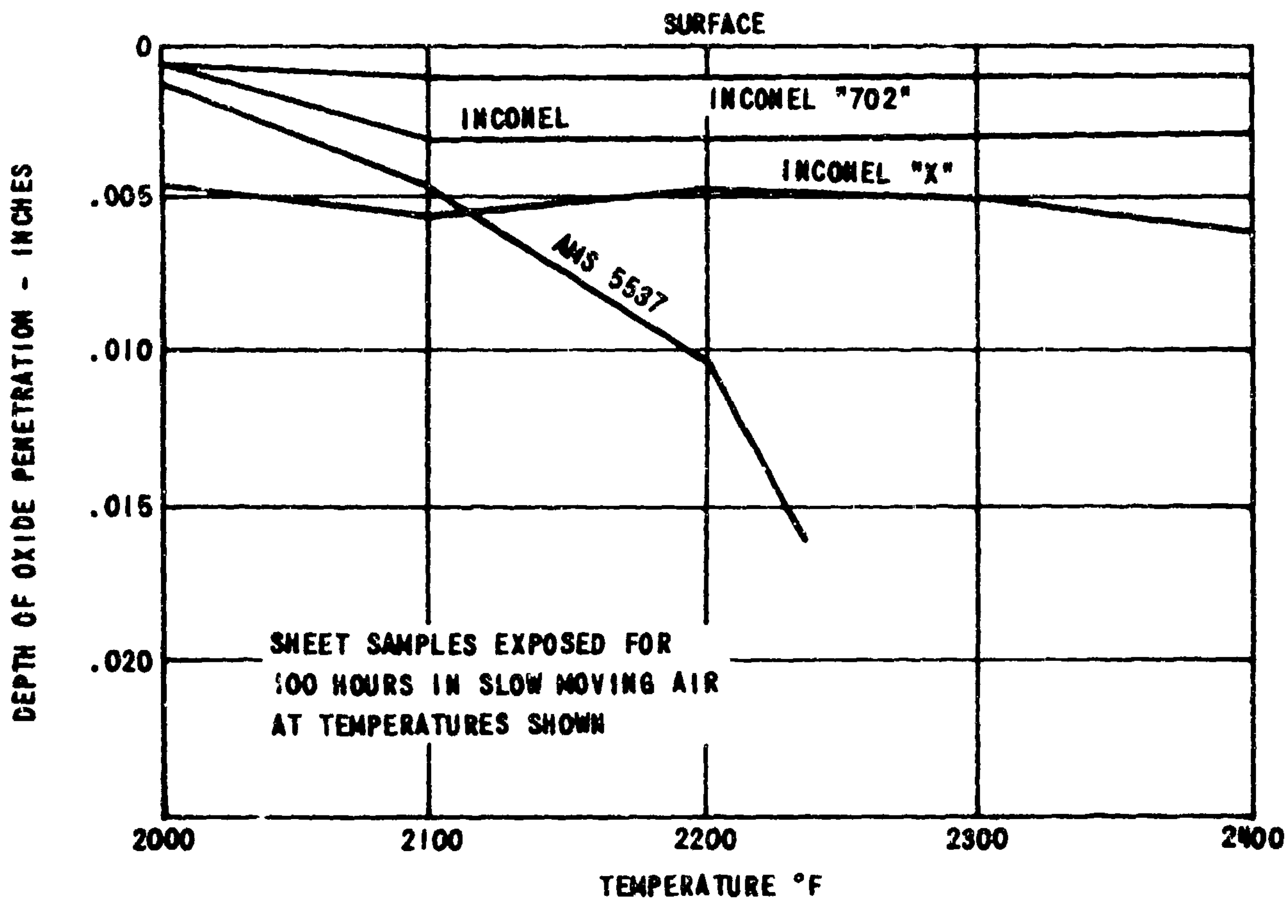


Figure 11 OXIDATION RESISTANCE OF INCONEL

Protective Coatings

Materials which have attractive strength characteristics at high temperatures but which do not have suitable oxidation resistance at such temperatures must be provided with protective coatings. Such a coating must have a thermal coefficient of expansion reasonably matched to that of the base metal. It must also flex to the same degree as the base material and it must withstand abrasion and thermal shocks dictated by the proposed application. A fractured protective coating loses its value and may result in a catastrophic failure Typical of the reduced oxidation which can be obtained through the use of a protective coating is shown in Figure 12 for calorized TD nickel. The greatly increased rate of oxidation due to a coating failure is shown in Figure 13. Protective coatings provide reliable protection for progressively shorter periods of time as the environmental temperature increases. The presently developed coatings for tantalum and niobium for example retain their usefulness for a hundred hours at a temperature of 2500°F, but will provide protection for only one hour at about 3000°F at a pressure of one atmosphere. Figure 14 shows this characteristic. The protective capability of some coatings is degraded in an environment of reduced pressure. Figure 15 shows such shortening of protective life with a reduction of ambient pressure.

The requirement of high strength at temperatures in excess of 2000°F has generally dictated the use of refractory metals, particularly niobium, molybdenum, tantalum, tungsten and their alloys. The protective coatings* required by these metals not only have a limited life and modify the structural behavior available from an uncoated metal, but they also have an emittance different from that of the uncoated metal. This property is also of importance in re-entry vehicles because a high emittance value enables a material to radiate heat and limit its temperature rise.

Representative of the protective coatings applied to niobium is the Chromium-Titanium-Silicon process of the Thompson-Ramo Wooldridge Corporation. This process consists of a titanium precoat applied for six hours

*Properties of Coated Refractory Metals, DMIC Report 195, January 1964, Battelle Memorial Institute, Columbus, Ohio.

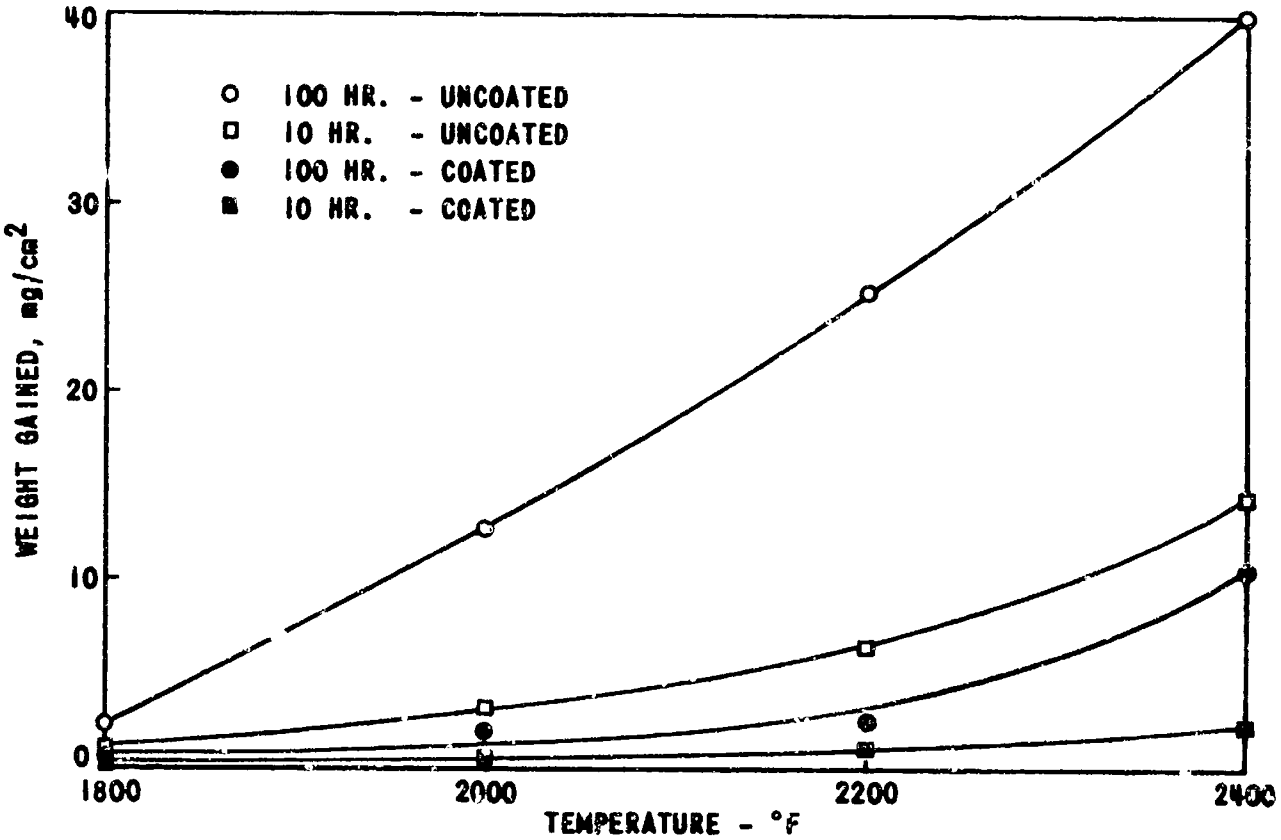


Figure 12 COMPARISON OF OXIDATION DATA FOR COATED AND UNCOATED TD NICKEL

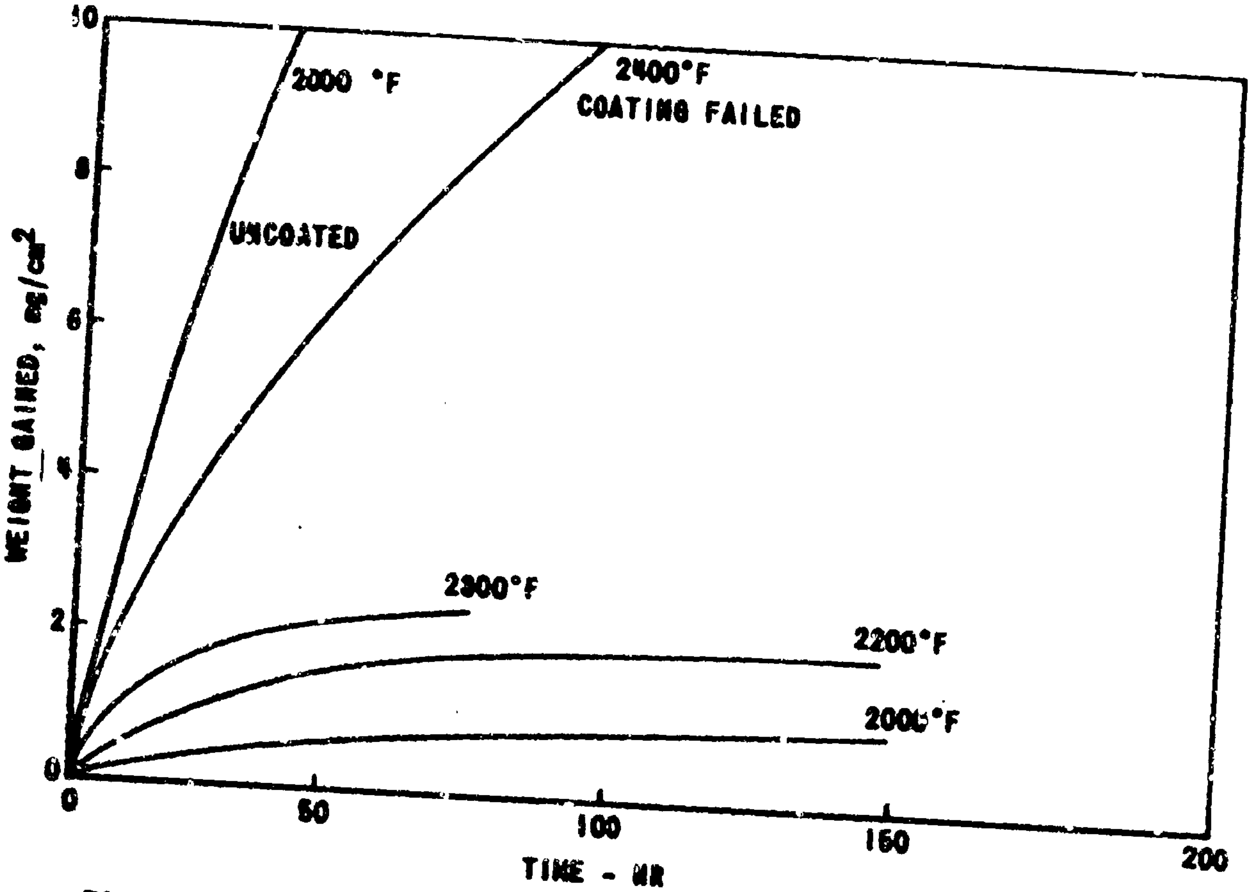


Figure 13 OXIDATION CURVES OF CALORIZED TD NICKEL

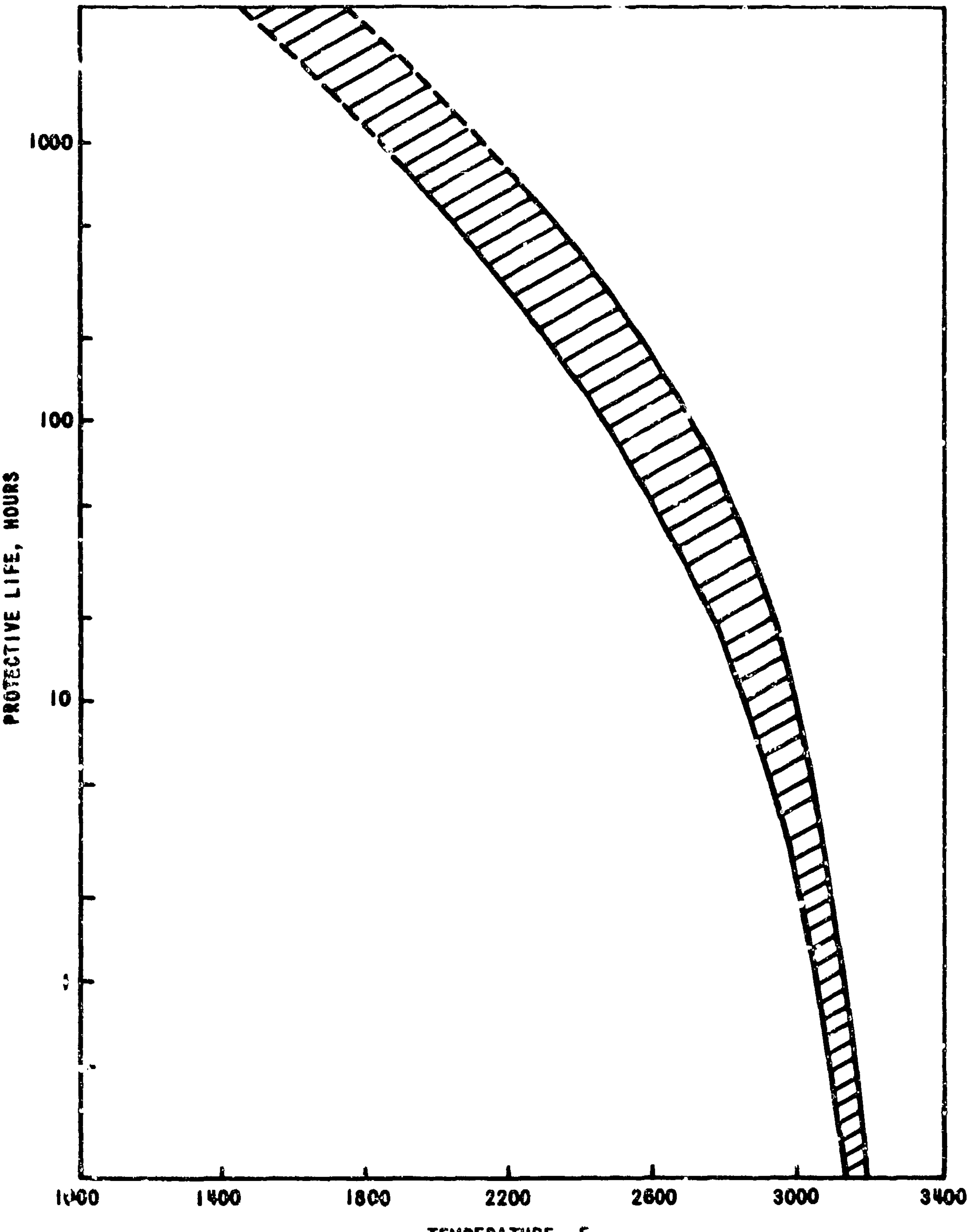


Figure 14 PROTECTIVE LIFE OF Cr-Ti-Si COATING ON NIOBIUM

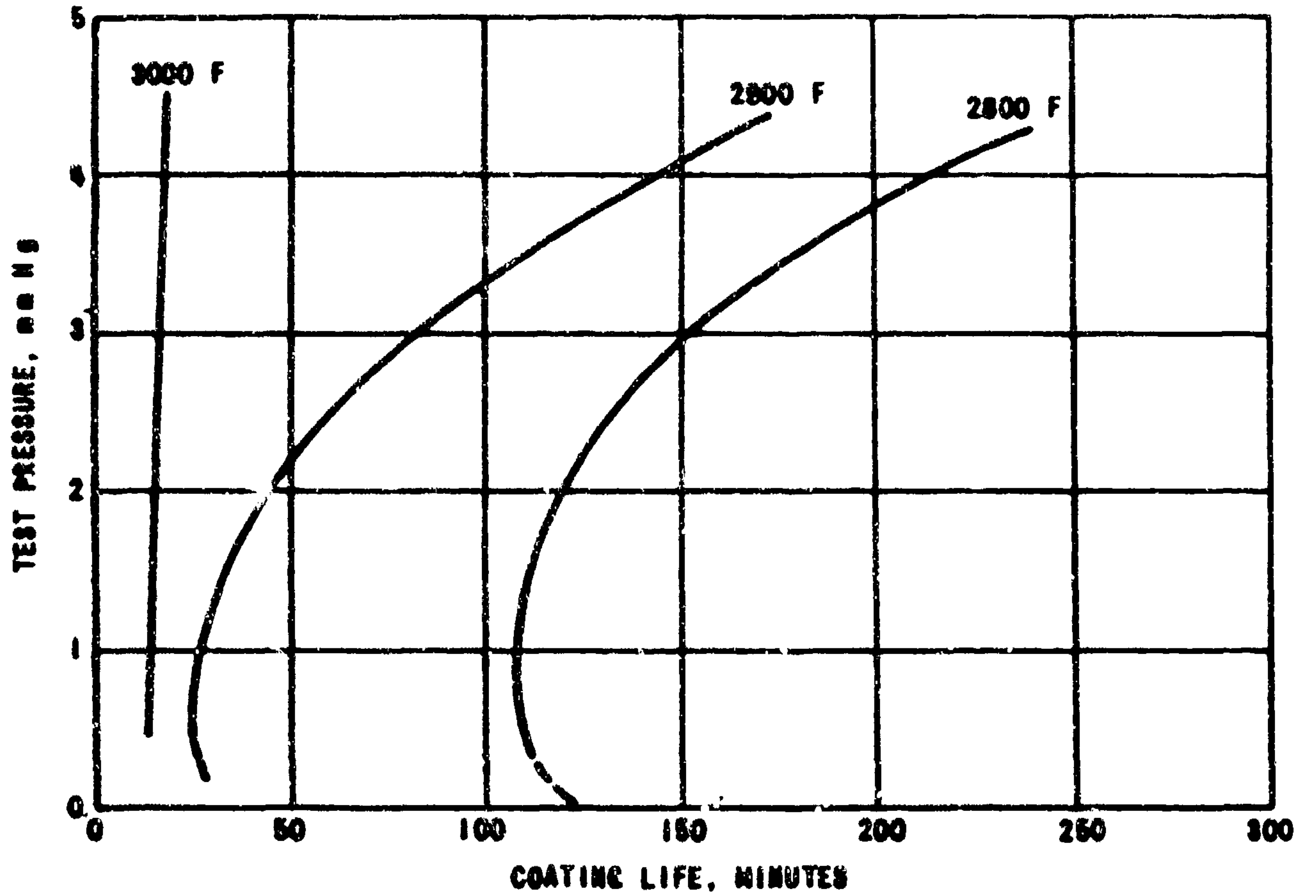


Figure 15 PROTECTIVE LIFE W-3 COATING ON MOLYBDENUM

at 1900°F, a Cr-Ti codeposition applied for eight hours at 2300°F and lastly a silicon deposit applied for four hours at 2000°F. The overall coating is 0.003 to 0.004 inches thick. Experiments were performed to determine the effects of high temperatures at low pressures which exist during re-entry. In a specific test a coated sample was heated to 2500°F for four hours at a pressure of 10^{-2} mm of mercury. Subsequent protective life of the coating exposed to 2500°F at one atmosphere of pressure was six hours. This coating normally has a life in excess of 100 hours at 2500°F and at one atmosphere of pressure.

The coated niobium retains substantially all the physical properties of the uncoated metal. Emittance data on the Thompson-Ramo Wooldridge coating is not available.

The Boeing Aircraft Company has developed an emittance-improved coating for niobium. The Boeing oxidation resistance coating is a straight silicide coating about 0.0015 inches thick. The emittance-improved coating is produced by applying an overlay of silicon carbide. An emittance of 0.8 to 0.96 under conditions of temperature and air pressure typical of re-entry was achieved.

Molybdenum has attractive strength-to-density characteristics in the 2700°F to 3000°F temperature range. A specific experiment to determine the effects of high temperature and low pressure typical of re-entry environment showed that a 30-minute life at one atmosphere of pressure could be attained also at a pressure of 0.2 mm of mercury by reducing the test temperature 450°F. The molybdenum protective coatings have an emissivity which is typically about 0.65.

A good protective coating for tantalum is the tin-aluminum coating developed by the General Telephone and Electronics Corporation. A solution which is 90% (Sn-25 Al) and 10% T_aAl_3 is mixed with a lacquer and then sprayed on tantalum. The coated material is heated for one-half hour at 1900°F during which an aluminide is formed. The process is then repeated to build up the coating to a thickness up to 0.006 inches. The coating has a life of one hour at 3300°F at one atmosphere of pressure, and 100 hours at 2000°F. Low pressures cause a loss of this coating through volatilization.

70% of the coating is lost through this process in 30 minutes at 2600°F at 1.5 mm air pressure. The coating is stable at 2600°F at a pressure of 3 mm. It is stable at 2800°F at a pressure of 6 mm.

Typical coatings also have short lives at specific narrow temperature ranges less than 3000°F. Such oxidation peculiarities of one coating are shown in Figure 16 which shows poorer oxidation resistance at 1800°F than at 2200°F. A titanium-modified silicide coating has shown a capability of eliminating such a failure at 1800°F in one tantalum alloy. A vanadium-modified silicide was developed to make less severe a similar oxidation peculiarity in still another alloy. Emittance values of these coatings have not been published.

The capability of current protective coatings for tungsten provide protection for 10 hours at 3000°F and one hour at 3600°F. Protection above 3600°F is nil. Additional development is required to permit the use of tungsten at higher temperatures where it still retains good strength. The present coatings for tungsten show poor oxidation resistance at 1600°F - 1800°F.

Thermal Expansion

The thermal expansion of materials is of importance in glass- and ceramic-to-metal seals. Seals of this type are generally made with a chemical bond which is produced when the materials are placed in contact and heated to a high temperature. If the thermal expansion of the materials is matched, no stresses will be created at the joint during cooling. If an unequal thermal expansion does exist, a tensile or compressive stress will exist and may result in the rupture of the weaker material.

Since ceramics have much greater strength in compression than they do in tension, an external seal, i.e. ceramic surrounded by metal, is a preferred type of seal. Metals have a greater thermal expansion coefficient than ceramics and a brazed assembly of metal surrounding a ceramic will upon cooling place the ceramic into compression.

The expansion coefficient mismatch which can be accommodated is limited to the stresses which such materials can survive. Large differential expansions can be accommodated only by allowing the metal to deform.

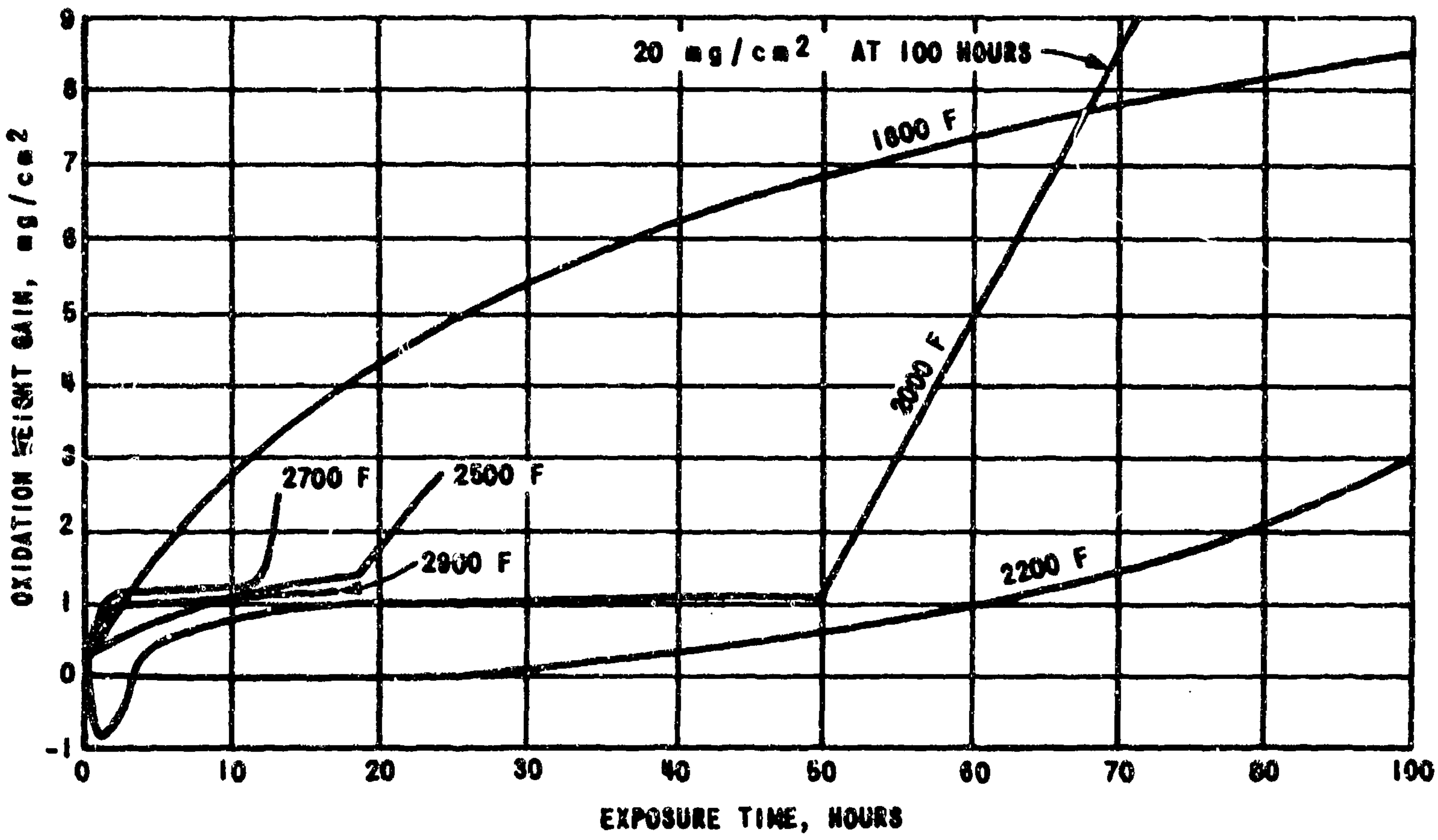


Figure 16 OXIDATION OF SILICIDE-COATED TANTALUM ALLOY

A corrugated metallic disk sealed around a ceramic body is a widely used deformable design. For temperatures of 1000 to 2000°F, differential expansion of 10 to 20 thousandths of an inch (per inch of material) must be accommodated.

Figure 17 shows the thermal expansion of representative high temperature metals and Figure 18 shows the thermal expansion of the more common ceramics. Niobium and alumina have closely matched thermal expansion properties. Mullite and molybdenum are also closely matched. Generally, the published information on the thermal expansion of ceramics is an average value from which considerable deviation can be expected. Figure 19, for example, shows the spread of values obtained in comparing data gathered by various investigators on materials supplied by a number of organizations.

Figure 20 shows the thermal expansion coefficients of specific nickel alloys which closely match the expansion characteristics of glasses. Metal-glass seals using these materials are suitable at the lower temperatures indicated. Sapphire sealed to a corrugated nickel alloy diaphragm is available for use to a temperature of 1700°F.

The initial process in producing a ceramic-to-metal seal requires metallizing of the ceramic. The most common of these is the moly-manganese process which consists of painting a ceramic surface with a mixture of molybdenum and manganese. Subsequent firing bonds this metal to the ceramic and on pure alumina can be expected to survive temperatures of 2600 to 3000°F in a non-oxidizing atmosphere. A brazing operation which joins this metalized ceramic to a metal uses brazing materials of low melting points and this is the reason that present-day widely-used seals are limited to about 1700°F. Brazes with higher melting points have been developed and some seals are capable of withstanding temperatures to 2700°F. The high temperature seal employs a palladium metal braze to join niobium to a tungsten metalized alumina ceramic. Palladium itself has good oxidation resistance but tungsten does not. The niobium-palladium-tungsten seal however should be evaluated for operation in a high temperature oxidizing environment because it is likely that the assembly may have a very low oxidation rate.

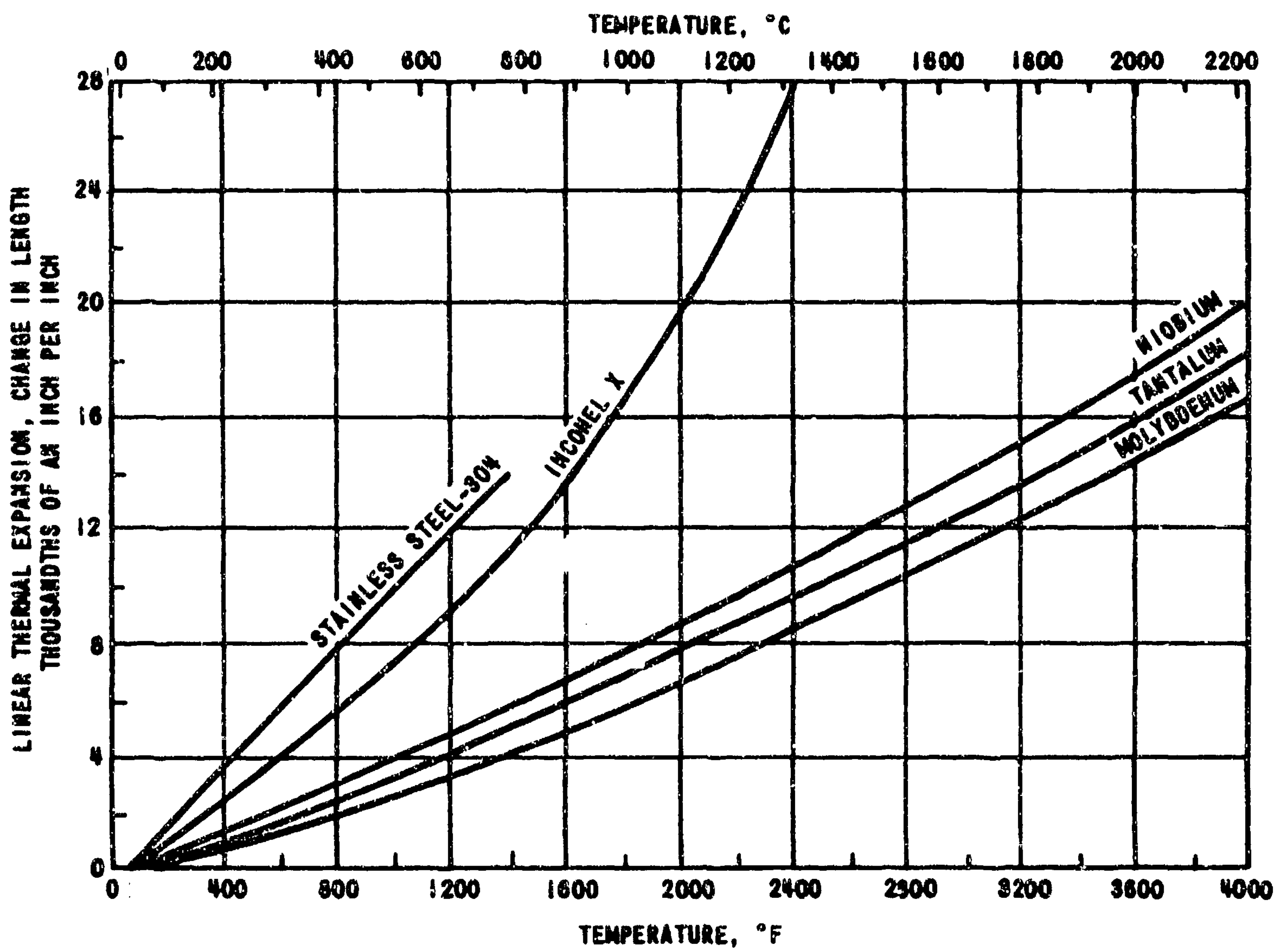


Figure 17 THERMAL EXPANSION OF METALS

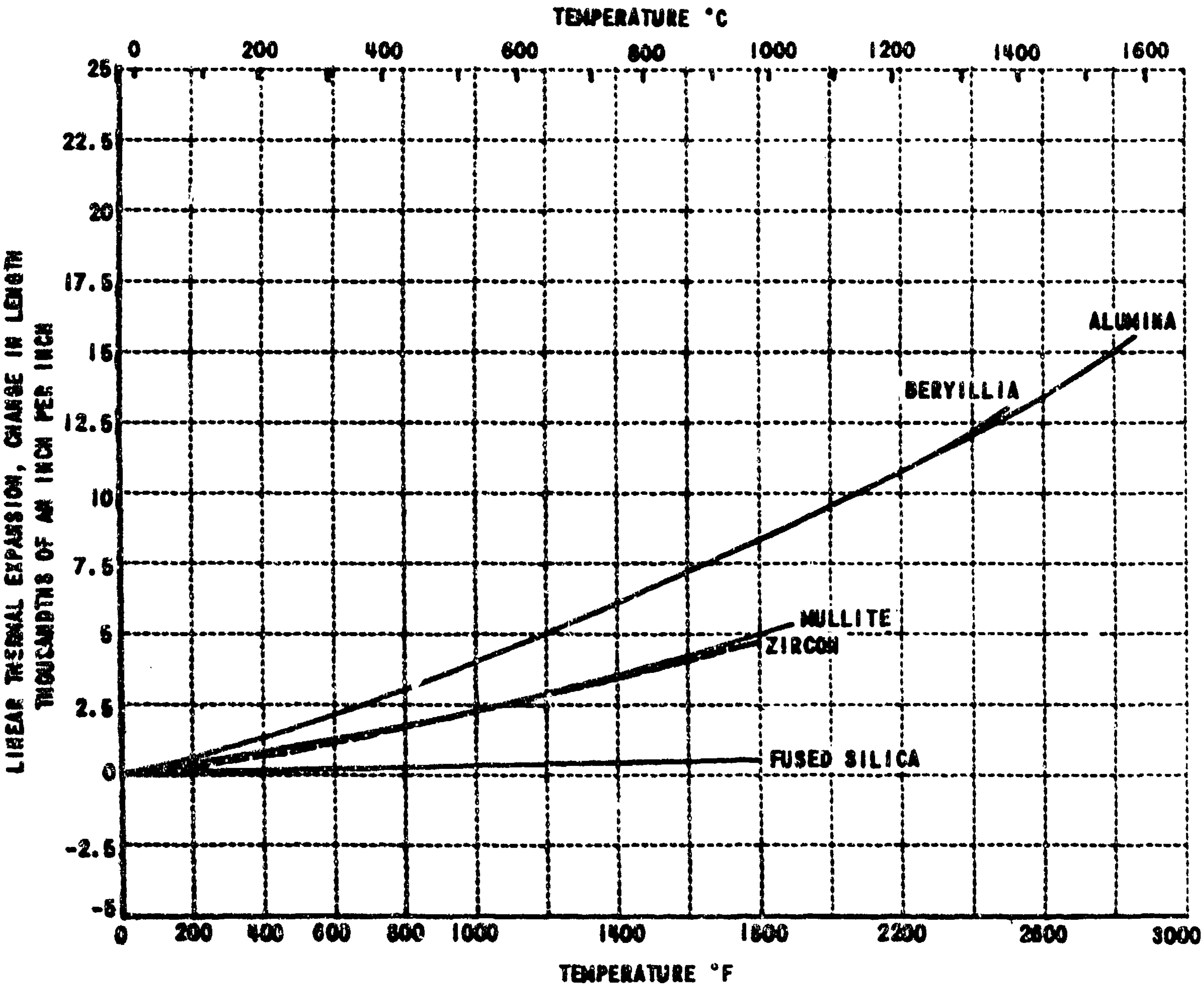


Figure 18 THERMAL EXPANSION OF DIELECTRICS

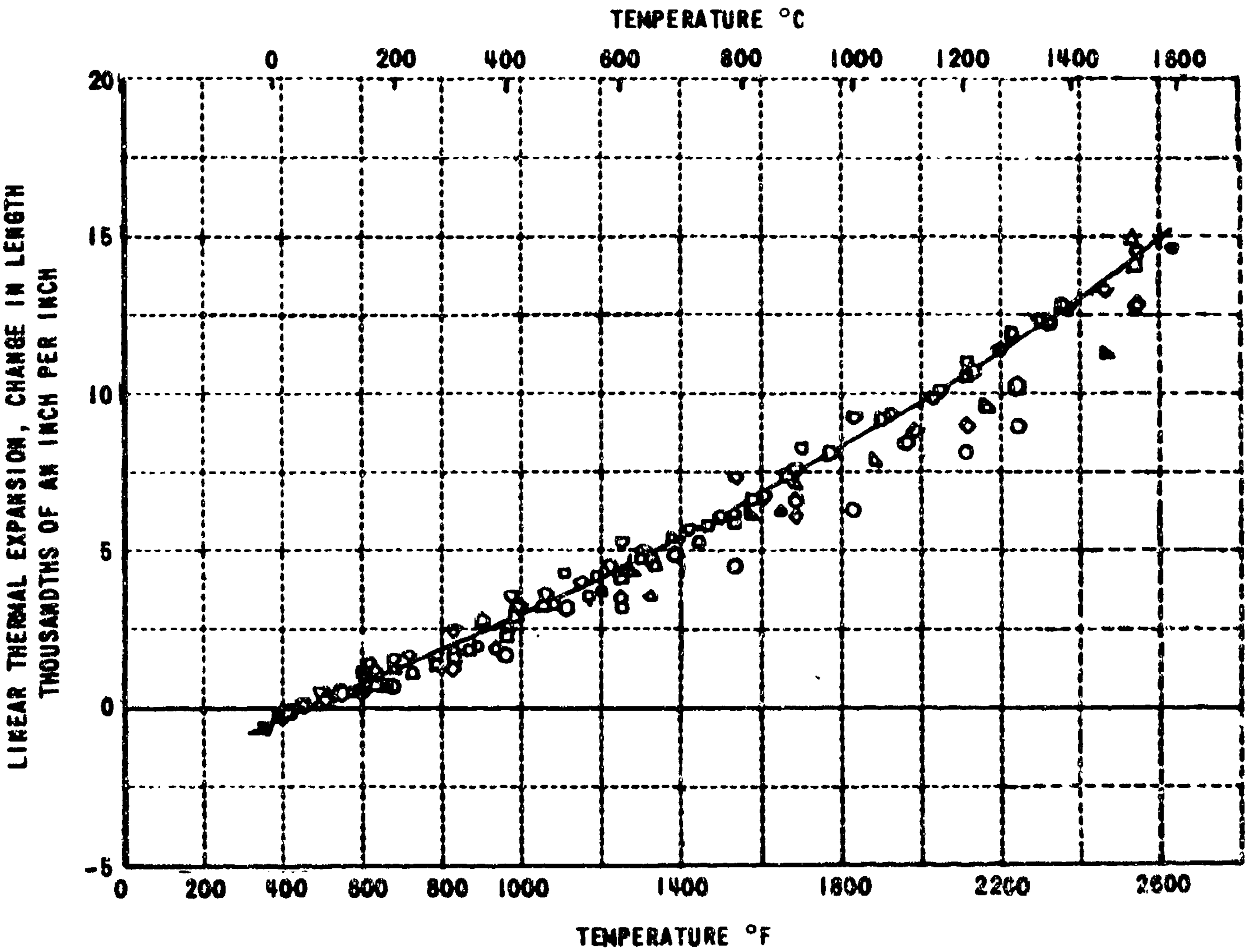


Figure 19 THERMAL EXPANSION OF ALUMINA - SPREAD OF VALUES

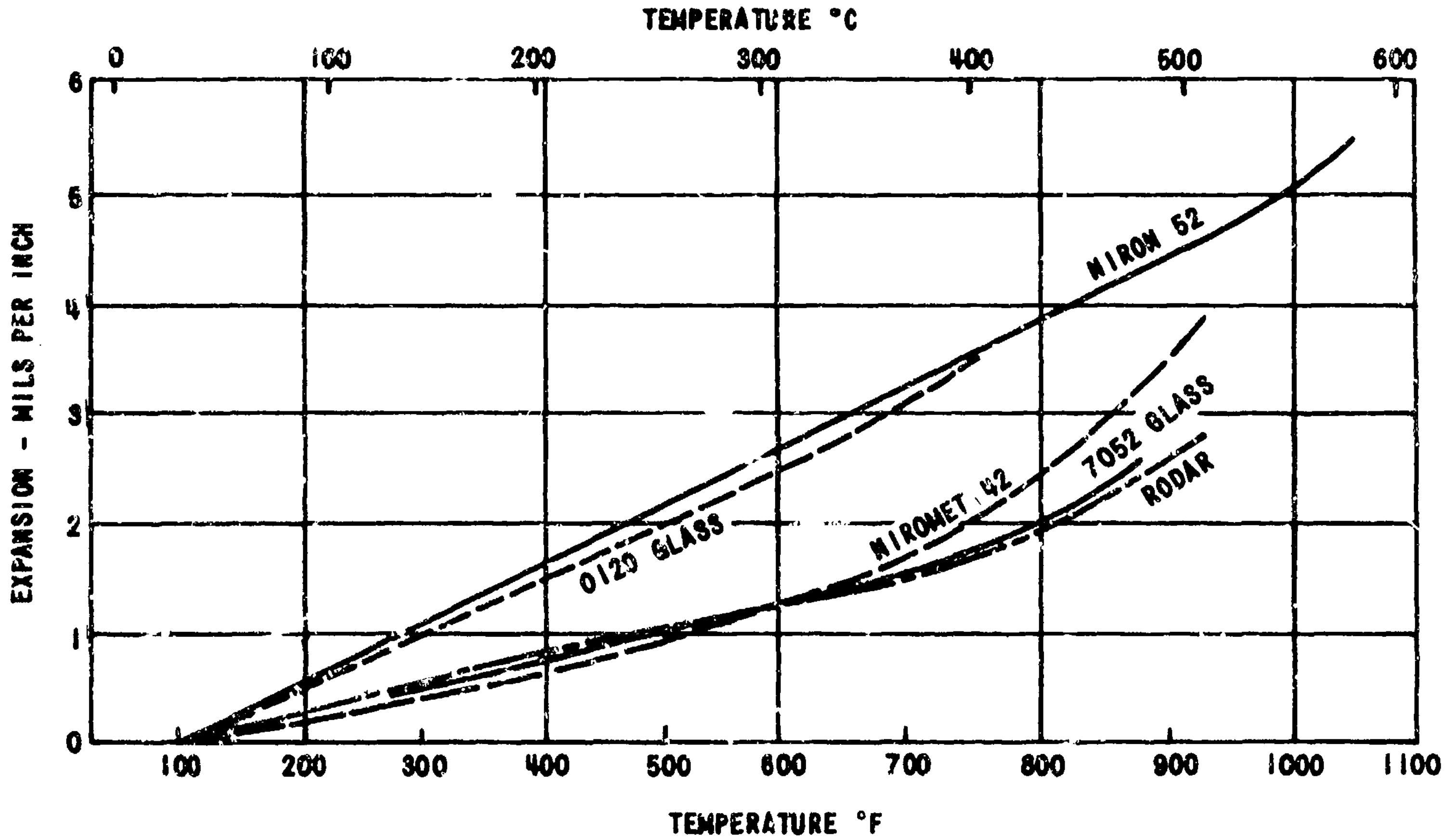


Figure 20 THERMAL EXPANSION OF GLASSES AND MATCHED METALS

Oxidation protection may be provided for assemblies using non-oxidation resistant materials by spraying on a protective coat of alumina. Alumina has attractive high temperature features for this purpose but it has porosity, and oxidation of the underlying metal will occur although at a slow rate.

The antenna range at the Wright-Patterson Air Force Base was used to measure the electrical performance of helical antennas made of conventional and high temperature materials. Specific measurements were made to compare the radiation efficiencies of identical antennas made of different metals. Additional tests were made on nichrome and tantalum antennas to determine any changes in electrical performance produced by a 2000°F thermal environment.

Helical antennas characteristically have an elliptical polarization. In order to compare the efficiencies of such antennas, radiation patterns were plotted automatically for two orthogonal polarizations for each of two mutually perpendicular elevation planes. The total area enclosed within these four radiation patterns is proportional to the antenna efficiency. A comparison of the total area of each of the helical antennas therefore was used as a measure of the relative efficiency of antennas made of different materials. This evaluation method has good accuracy as long as typical one-lobe radiation patterns are used as is the case in these tests. The two-turn S-band helical antennas used have a major lobe width of about 60°. Table 1 lists the total areas enclosed by the radiation patterns of antennas made of copper, stainless steel, nichrome and tantalum. The tantalum antenna had a tin-aluminide high temperature protective coating. The metals have resistivities of 2, 70, 120 and 20 microhm - cm, respectively. The value for the tin-aluminide coating (approximately 3 mils thick) is not known. An inspection of the data shows that a metal having a resistivity as high as 120 microhm - cm has no noticeable effect on the performance of these antennas. This finding is in agreement with a theoretical analysis developed by Ramo and Whinnery. Experimental verification serves to prove that fabrication methods may cause degradation. Considerable difficulty was experienced in coupling the coated fittings of the tantalum antenna and this is likely to be the major cause of the lower efficiency noted. These radiation tests also suggest that antenna efficiency tests may provide a method for establishing the microwave resistivity values of particularly low conductivity

TABLE 1

HELICAL ANTENNA

Comparison of Radiation Pattern Areas

Antenna Material	Area
Copper	25
Stainless steel	24.4
Nichrome	25.4
Tantalum (coated)	20.8

materials. Some of the newer materials (such as Boride Z*) which possess good oxidation resistance at high temperatures, for example, are produced by powder metallurgical techniques. Although construction of a helix from such material is difficult or impractical, this material can be flame sprayed on a dielectric substrate and a spiral antenna can be fashioned from it. A similar spiral made of nichrome of controlled resistivity can be used for an efficiency comparison test. High temperature data of this nature can also be obtained with relative ease.

Theory indicates that antennas made of very thin conductors will have efficiencies which are more sensitive to the metal's resistivity. To check this property, two six-turn helical antennas were made of 0.01" diameter wire. One was made with copper wire, and the other was made with nichrome. The efficiency data was compiled as before and an area ratio of 0.62 showed the nichrome wire antenna to be 4 db lower than the copper wire antenna. An appreciable error may exist in this analysis however since these helicies did not have end-fire operation at the test frequency. But the test does show the relative degree of importance that may be attached to the conductivity of materials used in antenna applications.

Tests to establish the effect of high temperature on antenna performance consisted of the above method of measuring the efficiency of the model

*A product of the Carborundum Co.

antenna at room temperature, a second efficiency measurement of the antenna enclosed in the thermal housing at room temperature and a third efficiency measurement made with the antenna and housing at 2000°F. These measurements showed that the thermal environment caused a decrease in efficiency of 6 db. It was still necessary to establish the proportion of loss introduced by the hot housing and it was proposed to evaluate this factor by first heating the housing without the antenna installed and then installing a cold antenna and record patterns before the antenna becomes hot for efficiency computations. The first attempt at this measurement showed that the antenna becomes hot very quickly - giving an insufficient time for recording patterns. To overcome this problem the antenna range equipment was positioned to monitor signal strength at the major lobe of the antenna when installed in the housing. The test antenna was removed, cooled, and then re-inserted into the hot housing. Signal strength was monitored as a function of time for two to three minutes. It is estimated that the antenna reached 2000°F in about one minute. The resulting change of signal strength vs time shown in Figure 21 is therefore representative of the change in antenna electrical performance as a function of temperature. The signal strength of the nichrome antenna is recorded as having increased 0.7 db with increase of temperature. Theoretical considerations suggest that the high temperature should produce no noticeable effect. No clear explanation is available to explain the above change although the variation may be within experimental inaccuracies.

A similar plot of signal strength with time for a coated tantalum helical antenna showed a negligible change with antenna heating to 2000°F. Figure 22 shows the data as it was recorded.

It is concluded therefore that this model antenna is insensitive to metal conductivity within the values used, and no significant electrical performance changes are caused by temperatures up to 2000°F.

VSWR measurements were made on the nichrome helix at room temperature with and without the thermal housing. VSWR measurements were also made with the antenna and housing heated to various temperatures up to 2000°F. These test values are shown in Figure 23. Intermediate temperature values are not indicated but lie between the curves shown.

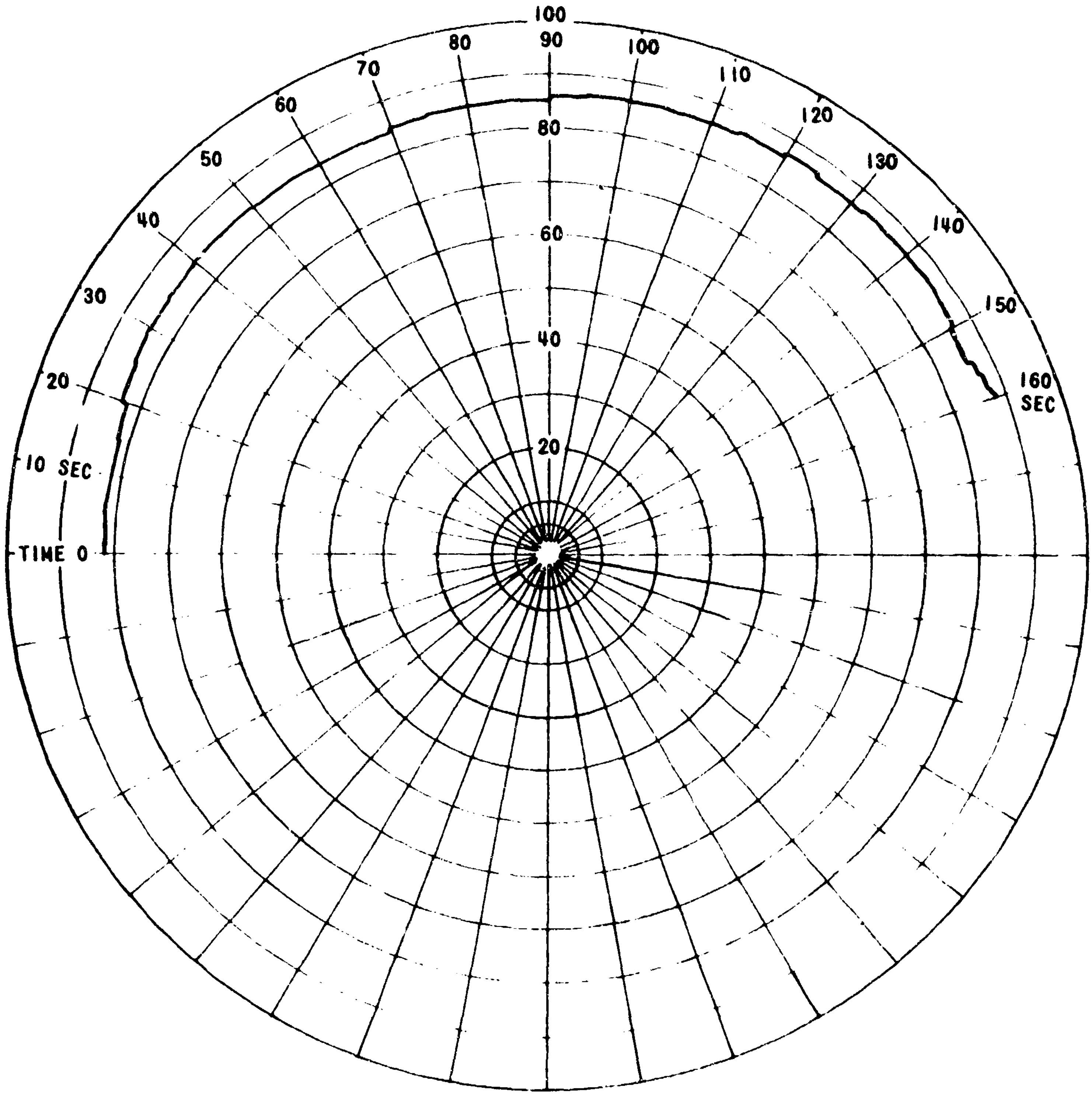


Figure 21 NICHROME ANTENNA SIGNAL STRENGTH vs TIME
ROOM TEMPERATURE TO 2000° F

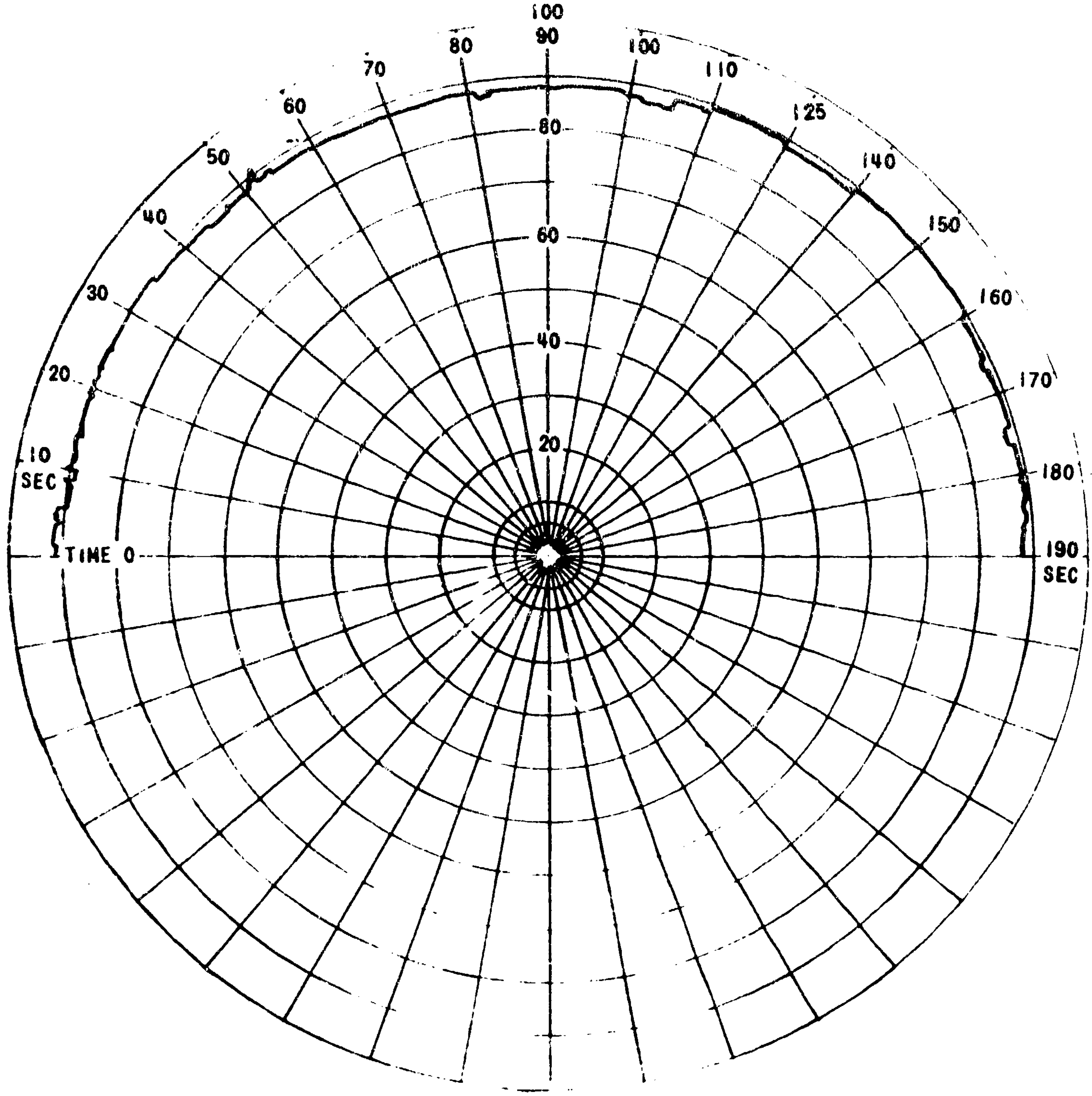


Figure 22 COATED TANTALUM ANTENNA SIGNAL STRENGTH vs TIME
ROOM TEMPERATURE TO 2000 F

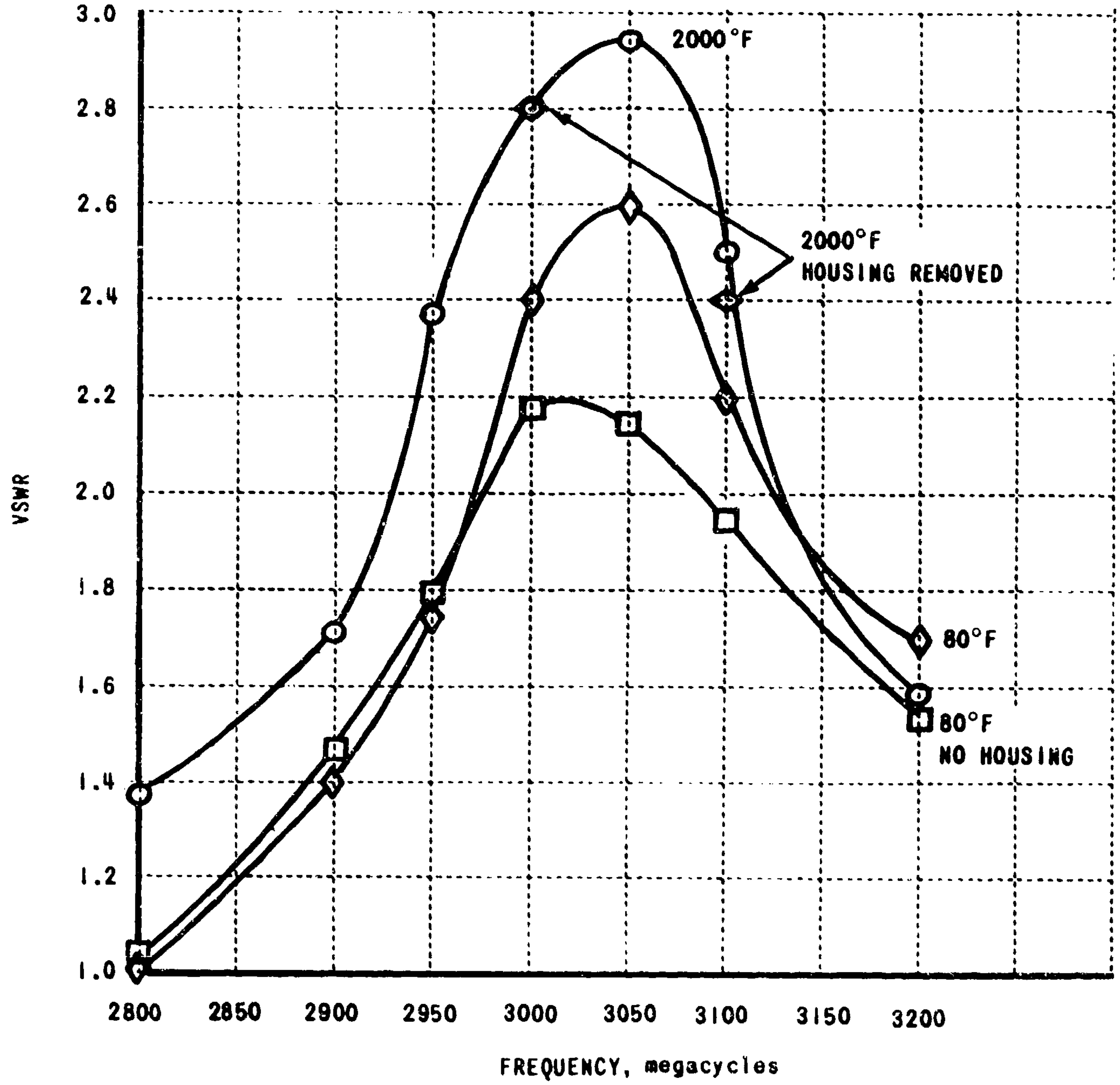


Figure 23 NICHROME HELIX AND HOUSING VSWR vs TEMPERATURE

It cannot be conclusively shown what magnitude of VSWR changes are caused by heating the antenna since the values measured included a length of coaxial cable, fittings, etc. It is to be noted too that two values were measured just after the assembly was heated to 2000°F and after the radome was removed. The antenna is estimated to have cooled by several hundred degrees in the time required to make these measurements. The values are seen to be largely unchanged from those obtained with the housing at 2000°F and in place over the antenna. In view of the housing effect on VSWR values at room temperature, its apparently transparent property at 2000°F does not seem correct. It is possible that the antenna adapter and fittings (because of oxidation or other heating effects) may account for the VSWR change noted from room temperature.

Further thought is being given to the possibility of using a swept-frequency reflectometer for measuring VSWR values quickly, and again employing the technique of inserting the antenna into a hot housing and recording data as the antenna becomes hot.

Figure 24 is a photograph of the S-band helical antennas used for tests. The complete assembly shown is the tantalum antenna with an aluminide protective coating applied by Sylvania. The coating is a bright aluminum color when applied and it changes to a dull grey color after being heated to 2000°F. An unmounted nichrome helical element is also shown on this photograph to illustrate the radiating element design.

Figure 25 shows both the coated tantalum antenna and the nichrome helical element (on a stainless steel ground plane) after exposure to 2000°F.

Figure 26 shows the model stub antennas which were made earlier to determine any design or temperature problem areas which might be overlooked from a purely paper study. The brass model served as a reference of electrical performance. Recorded radiation pattern of these antennas showed that all assemblies had equal efficiencies. Heating of the nickel plated and bare stainless steel assemblies (to 1500°F) produced discoloration of the surface and no apparent degradation in electrical performance. The niobium stub antenna was not given a protective coating because of the expense of this process and because plans were under way to coat a tantalum

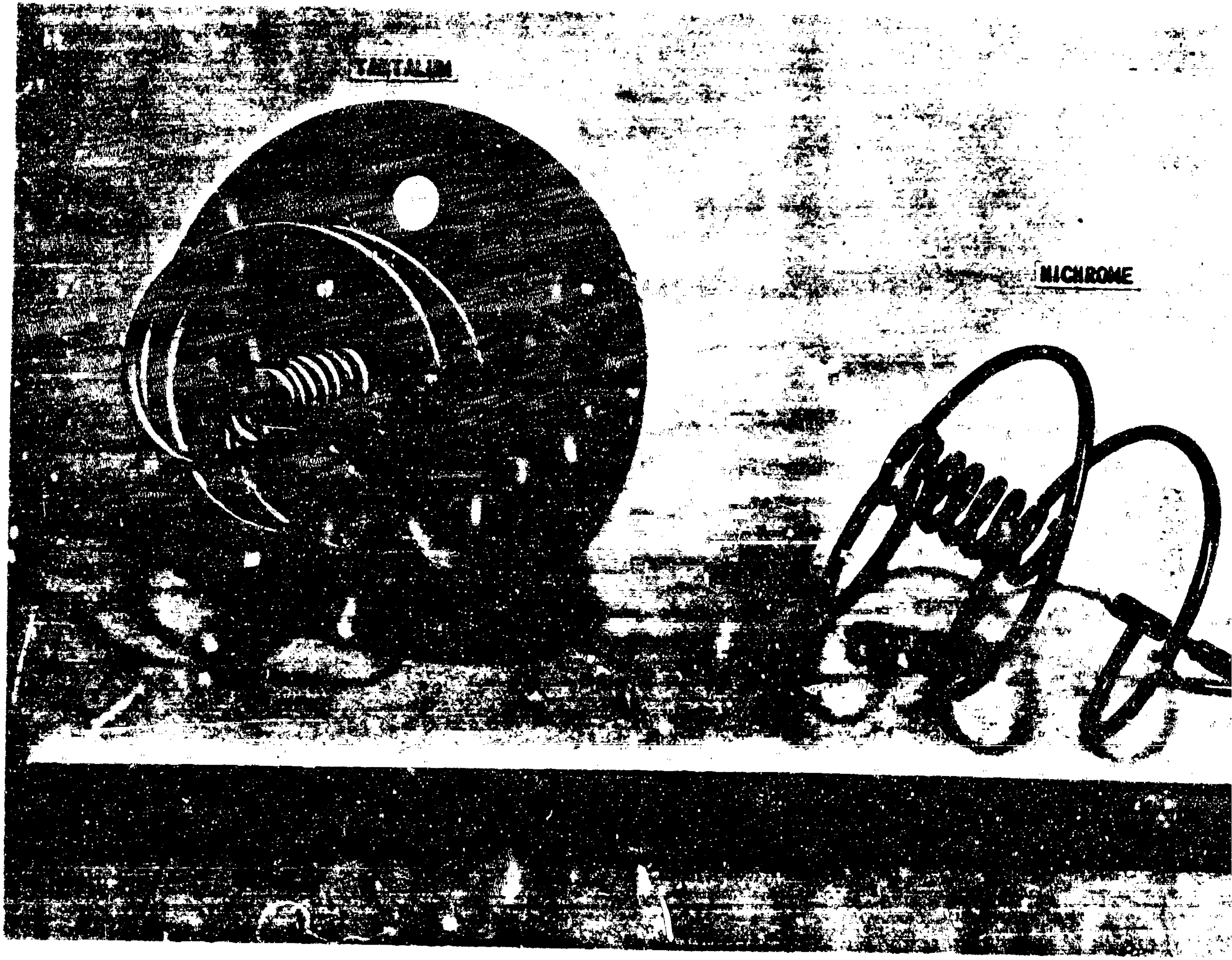
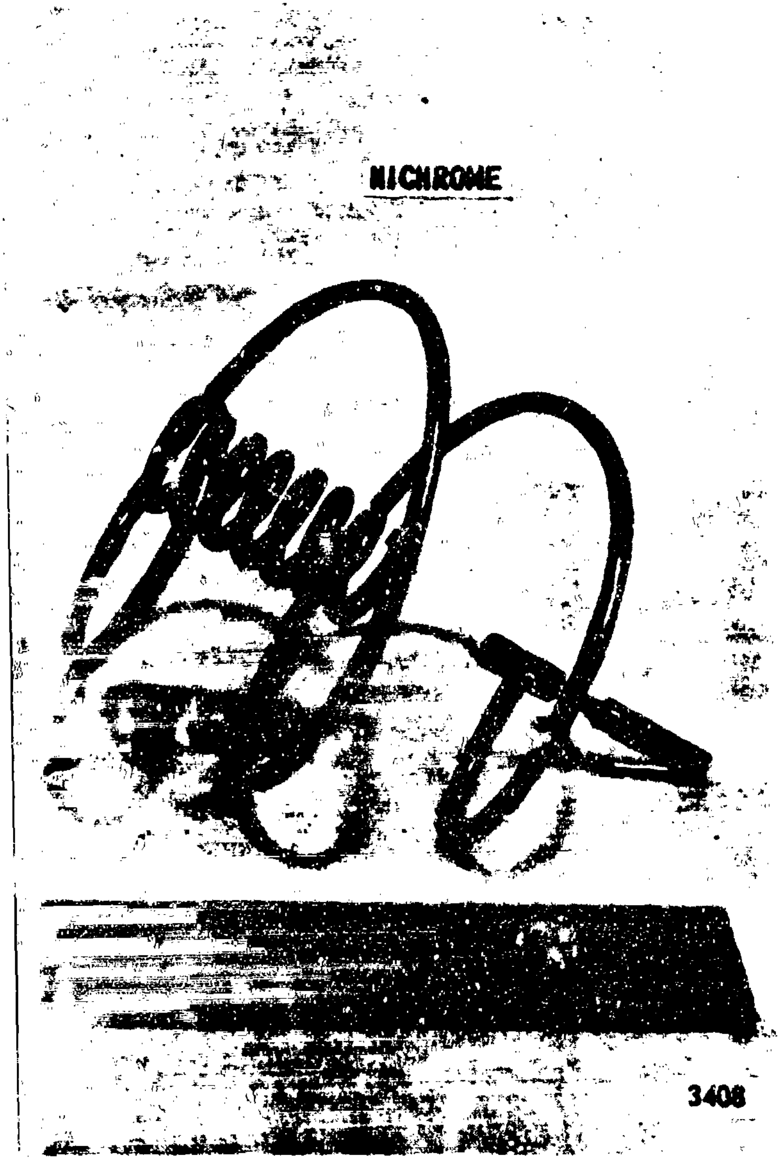


Figure 24 HELICAL ANTENNAS



ENNAS

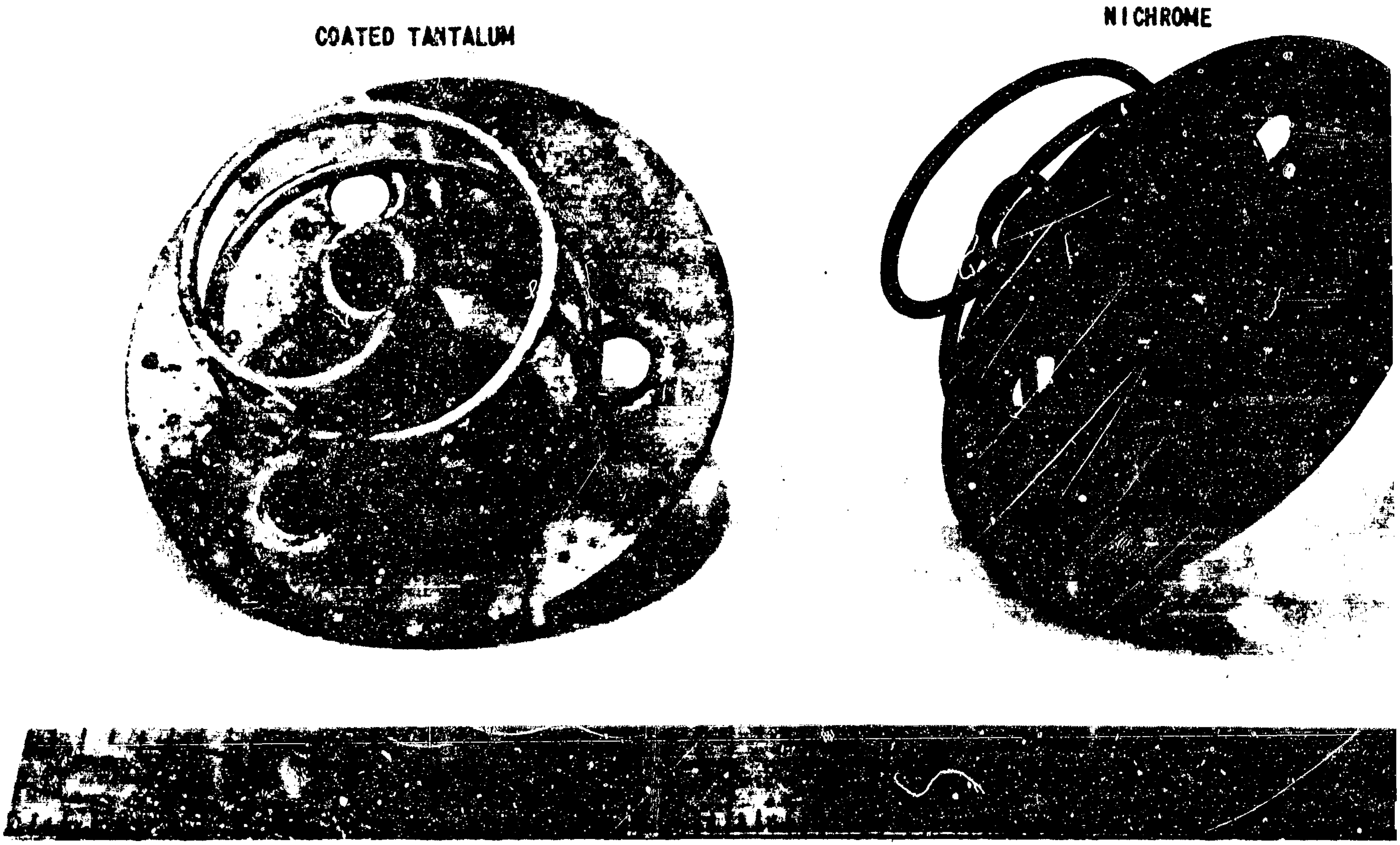


Figure 25   COATED TANTALUM AND NICHROME ANTENNAS AFTER HEATING TO 2000° F

Figure 26 STUB ANTENNAS

helical antenna and a niobium waveguide assembly with protective coats to provide test data on such coatings.

Threaded fasteners were found to be a source of difficulty. Corrosion of threaded fasteners results in seizing after exposure to high temperatures. Plans are under way to evaluate commercially available anti-seize compound which may be helpful to 2000°F. Plating (with nickel, for example) is helpful at reduced temperatures. The threaded parts which are to be plated must be specially modified to accommodate the increased thickness of the parts when plated. The usual modification consists of reducing the thread diameters of external threads by twice the plating thickness. Thread diameters of internal threads are increased by this amount. This modification is generally acceptable for conventional metal platings, however, the protective coatings applied to refractory metals do not build up uniformly and a fine thread cannot be coated without causing difficulty in mating coated threaded fasteners. Suitable coated refractory metal threaded fasteners should allow for a coating thickness variation of a few mils on each part. This strongly suggests that threaded parts of refractory metals be avoided if an alternate design exists, or if such parts must be used, coarse threads should be employed.

The possible degradation of the power handling capability of an antenna by a hot thermal environment is being experimentally determined. Power breakdown tests are being performed in a waveguide assembly in which samples of selected materials are heated to a temperature of 2000°F. Power handling tests of materials are being performed in this manner in order to avoid the modifying influence of dielectric supports, feeds and other physical peculiarities of antenna assemblies, and also the added complexity of having to design a suitable chamber for maintaining the antenna at 2000°F while it is simultaneously contained in a vacuum.

Figure 27 shows the experimental set-up used for the breakdown tests. S-band microwave power of about 1 kw peak is coupled to the test section enclosed by fire bricks. Silicon carbide heating elements inserted into the brick structure provide the necessary heat using a 60 cycle power input of 3 to 4 kw. A chromel-alumel thermocouple is used for temperature measurements and it also provides an input to circuitry which automatically controls the heating current to maintain a selected temperature at the test point. The thermal drop along the test section (a 12-inch long coated tantalum suitable for use at 3000°F) is rapid enough to allow the use of copper waveguides for adjacent sections. Cooling coils are soldered on these copper waveguides to insure the existence of suitable low temperatures at the conventional waveguide windows located at the next flange assembly. A one millicurie Cobalt 60 radioactive source is positioned on the test waveguide during breakdown measurements. The function of the radioactive source is to give repeatability of measurements. Figure 28 illustrates the repeatability which can be achieved by this method. Breakdown test points on the solid line were consistently recorded using the Cobalt 60 source, while the spread of values obtained at various pressures without the use of Cobalt 60 is shown by the X's. Breakdown with the source shows what appears to be a pessimistic value, however it is believed that power handling capabilities as low as that observed with the radioactive source would have been observed if a longer observation period were employed for each test point. The power breakdown procedure

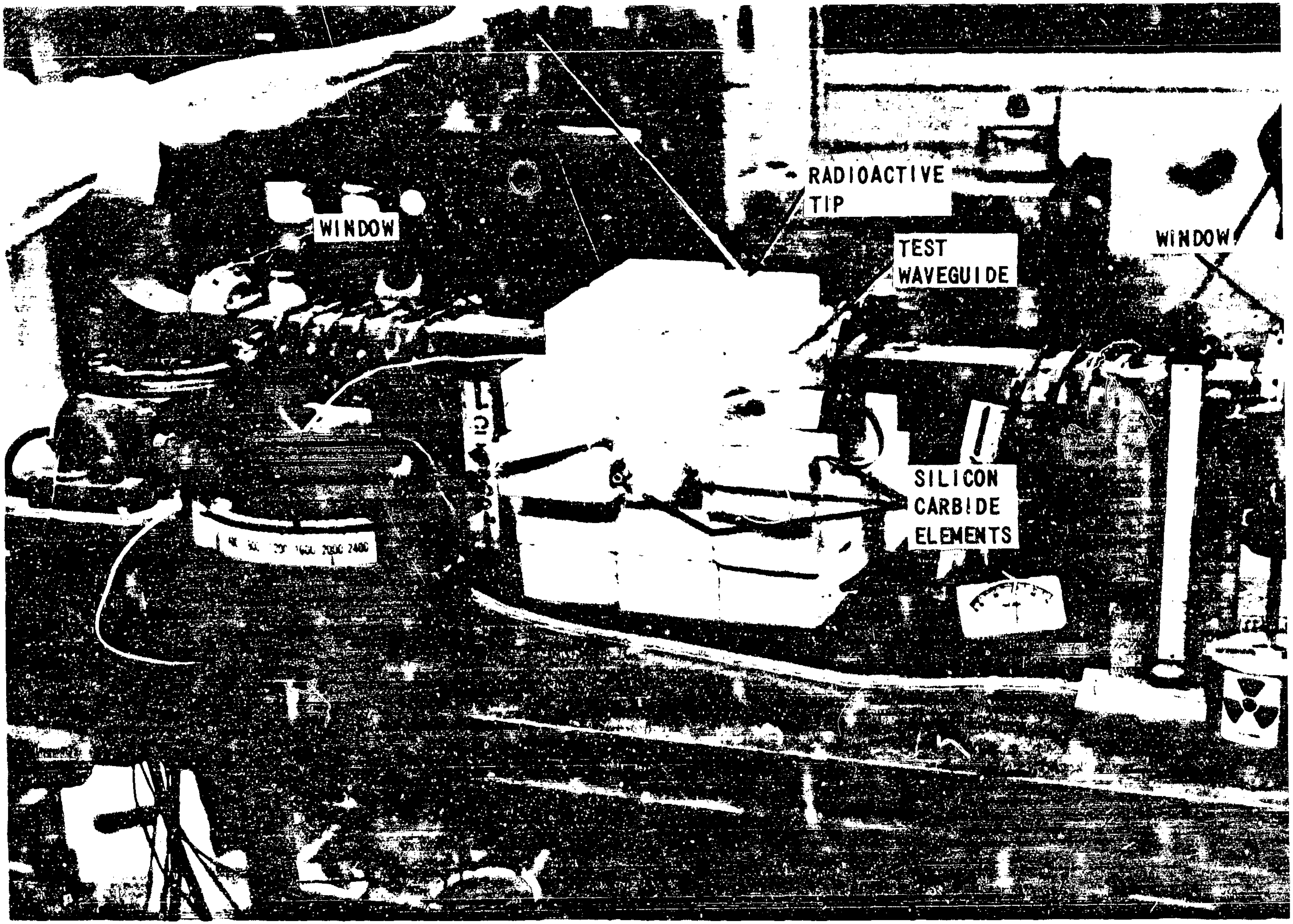
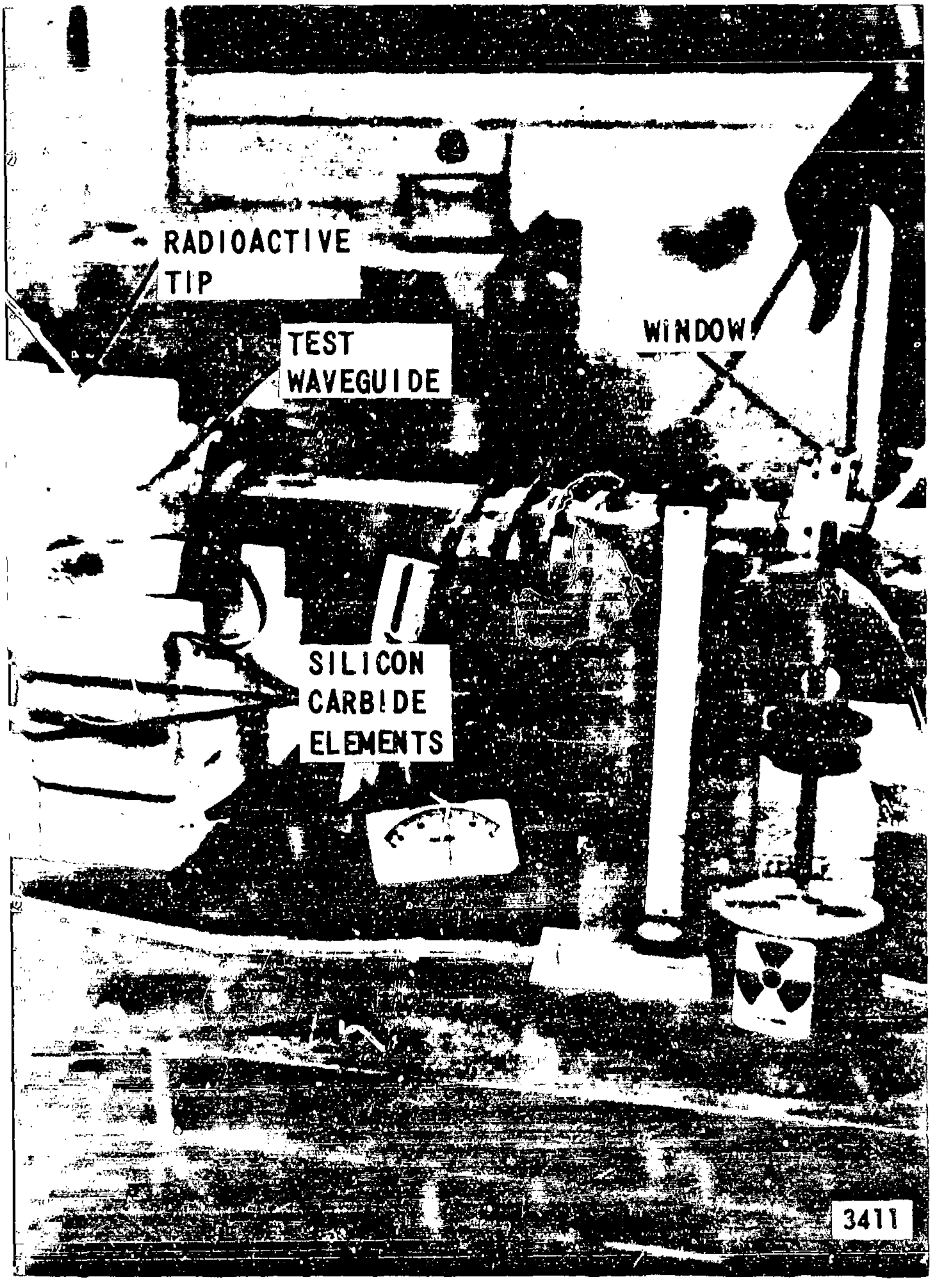


Figure 27 POWER HANDLING TESTS



R HANDLING TESTS

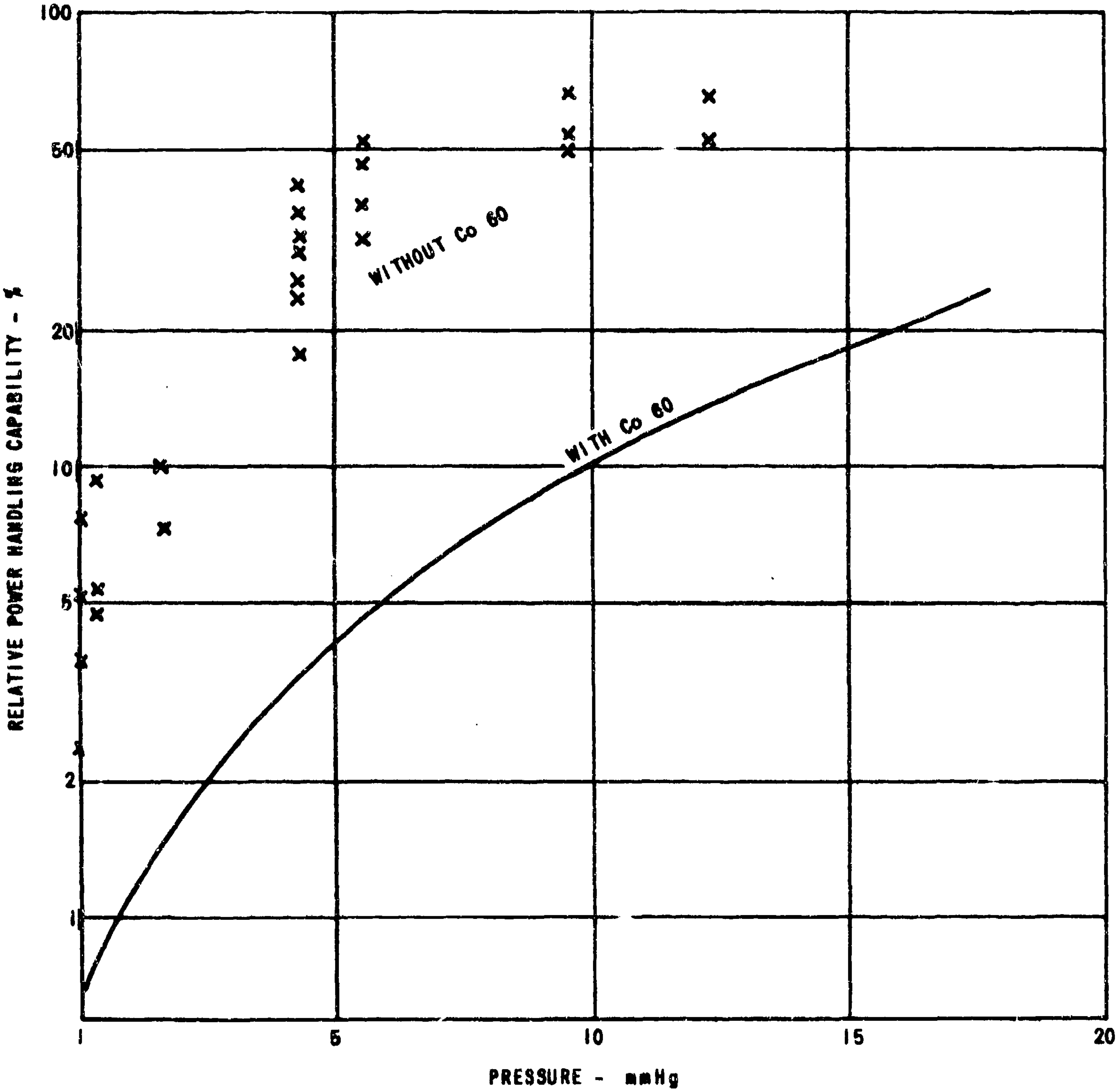


Figure 28 COMPARISON OF REPEATABILITY OF DATA WITH AND WITHOUT COBALT 60

consists of setting a selected pressure environment and then slowly increasing the incident power until breakdown is produced. It is argued that the breakdown occurs when a suitable ionizing event (from background ionization present in the laboratory) enters the waveguide in time coincidence with the pulsed microwave energy. Since such coincidence occurs very infrequently, the "slowly increasing of microwave power" for breakdown tends to rise above the breakdown threshold before the coincidence occurs and an apparent higher power capability is recorded. The same reasoning can be used to explain the spread of breakdown values. Investigators have shown that a given power setting may have to be maintained for an hour or more before re-adjusting it to a higher level with assurance that the inherent power handling capability of a device is not being exceeded. If a radioactive source is used breakdown readings may be taken at intervals of less than one minute.

Breakdown tests were run on a waveguide in which two hemispheres 0.335 inches in radius were located on the centerline of the broad wall and spaced to produce an electrical match. Copper hemispheres at room temperature had a power handling vs pressure characteristic as shown in Figure 29. Minimum power handling occurs at a pressure of about 2 mm Hg and the power handling capability rapidly increases with increasing pressure. At higher temperatures, approximately the same minimum power handling capability is noted except that it occurs at higher pressures. This characteristic is in agreement with theory which states that power handling is a function of gas density. The density which exists at a selected pressure at room temperature can be reached at high temperature only by increasing the pressure. This cold (25°C) to hot pressure ratio is proportional to 293/T where T is the hot temperature in degrees Kelvin. Figure 29 shows the variation of power handling noted in tests of copper hemispheres at various elevated temperatures. A curve is shown for the assembly after cooling to 150°F which shows the degree of experimental stability which existed over the testing interval.

Figure 30 shows the results of similar tests on coated tantalum hemispheres. These curves show a decrease in the minimum power handling capability at high temperatures.

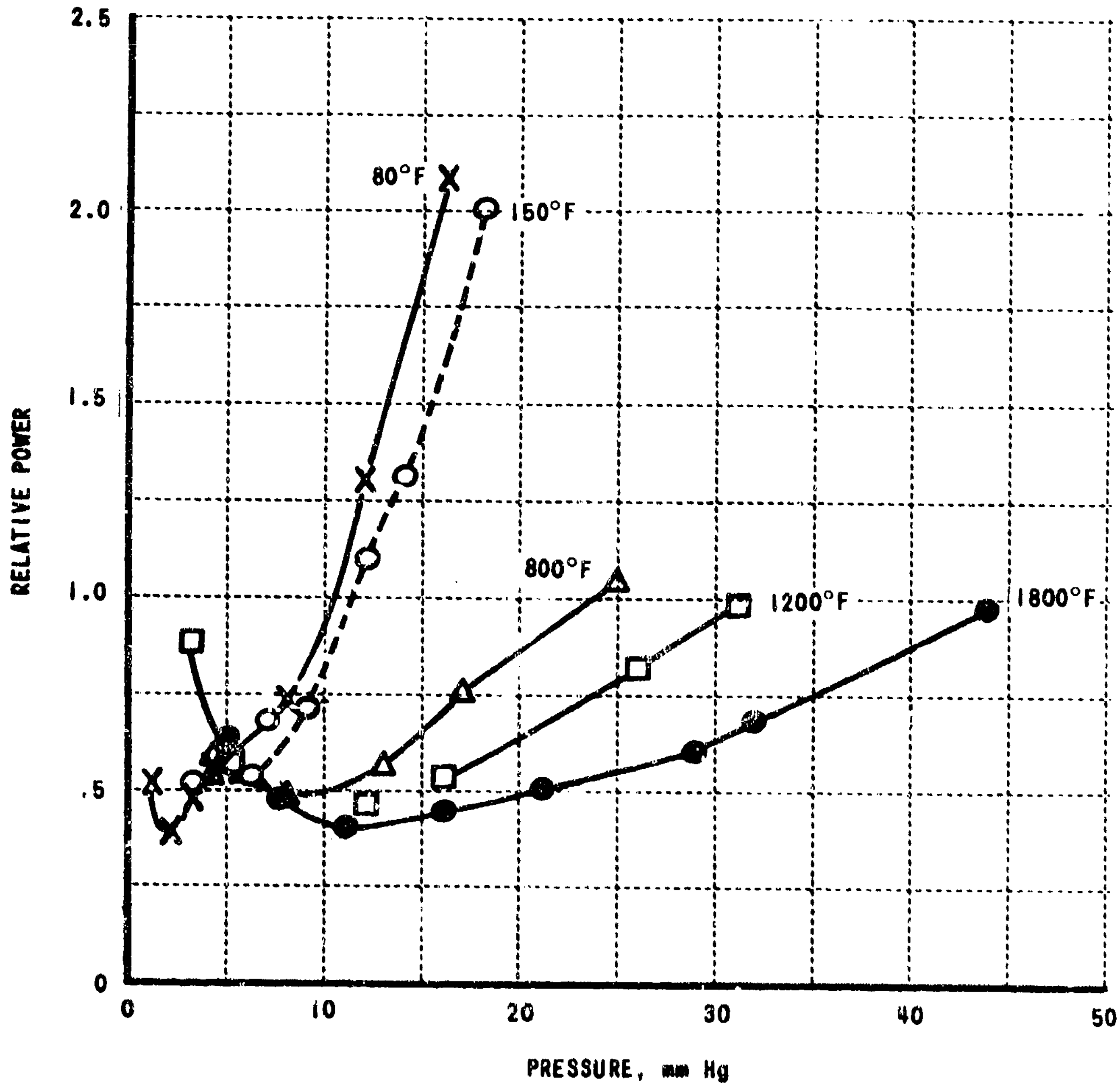


Figure 29 BREAKDOWN OF COPPER HEMISPHERES

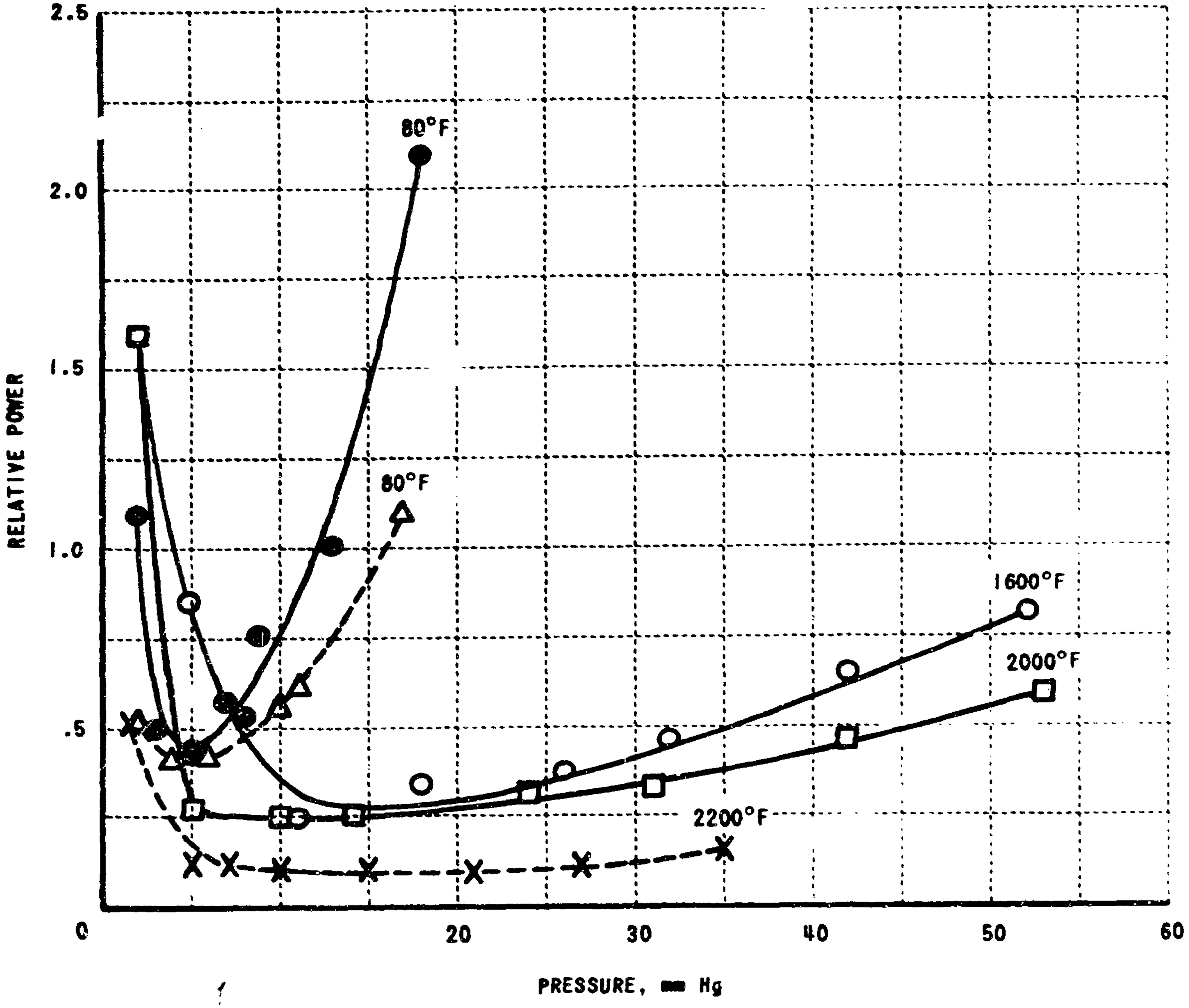


Figure 30 BREAKDOWN OF COATED TANTALUM HEMISPHERES

CONCLUSIONS

The results of investigations to date have shown that nickel alloys (super alloys) are usable as antenna materials for temperatures up to 2000°F. Coated refractory metals should be used above this temperature. The coated refractory metals have greater strength than super alloys at 2000°F, but the need for protective coatings and the possibility of damage to such coatings and the need of special facilities for fabrication are strong arguments against the use of refractory metals if super alloys can be used.

The electrical performance of model antennas made of high temperature materials has shown no degradation with temperature, and room temperature performance is comparable to that of antennas made of more conventional materials.

Preliminary tests on the power handling capability of various high temperature materials show that this characteristic is comparable to that of copper.

RECOMMENDATIONS

All evidence to date shows that high temperature metals are electrically suitable for use in microwave antennas but particular attention should be paid to threaded parts. If coated refractory metals are used, coarse threads must be used to avoid problems from a non-uniform buildup of the coating.

The re-entry thermal environment should be studied further since it appears that a surface temperature of 2000°F for a limited time may not cause the temperature of a component close to the surface to attain a temperature in excess of 1000°F. Thus portions of an antenna not directly associated with the surface of a re-entry vehicle can use nickel alloys with greater confidence.

The power handling capability of an antenna at high temperature is degraded from that achieved at room temperature because of the lower air density which exists at high temperature. The high temperature which exists at re-entry may cause breakdown of antennas which have been designed to operate at the anticipated re-entry pressure without taking into account the high temperature. Tests should be made on selected antenna assemblies to clarify the degradation to be expected.

REFERENCES

Information contained in this report has been obtained from a large number of sources and used directly or combined to present relationships illustrating various characteristics of interest to this investigation. Sources from which much related data has been abstracted are:

The Current Status and 1970 Potential of Selected Defense Metals. DMIC Memorandum 183, October 1963, Battelle Memorial Institute, Columbus, Ohio

An Investigation of a New Nickel Alloy Strengthened by Dispersed Thoria. TND-1944, July 1963, National Aeronautics and Space Administration

Summary of the Seventh Meeting of the Refractory Composites Working Group. DMIC Memorandum 184, May 1963, Battelle Memorial Institute, Columbus, Ohio

Recommendations and Evaluations of Materials - Research Areas of Importance to Missile and Space Vehicle Structures. TN D-2125, October 1963, National Aeronautics and Space Administration

An Analytical Investigation of the Loads, Temperatures, and Ranges Obtained during the Recovery of Rocket Boosters by Means of a Parawing. TN D-1003, February 1962, National Aeronautics and Space Administration

A Review of the Refractory Metals. LR-358, November 1962, National Aeronautics Establishment, Ottawa, Canada

Properties of Coated Refractory Metals. DMIC Report 195, January 1964, Battelle Memorial Institute

Temperature Effects on Material Characteristics. CoA Report No. 135, August 1960, The College of Aeronautics, Cranfield, England

Thermophysical Properties of Solid Materials. Report 58-476, November 1960, Wright Air Development Division

Much helpful information was also obtained from technical literature of the DuPont Company, the International Nickel Company and others.